UNCLASSIFIED

AD NUMBER
ADB014260
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; MAY 1976. Other requests shall be referred to Air Force Armament Laboratory, Attn: DLMQ, Eglin AFB, FL 32542.**
AUTHORITY
ADTC ltr, 3 Jul 1979

THIS PAGE IS UNCLASSIFIED

TECHNICAL REPORT AFATL-TR-76-26

AIR FORCE ARMAMENT LABORATORY INFRARED PLUME SIMULATION CAPABILITIES

TARGETS BRANCH

GUIDED WEAPONS DIVISION

MAY 1976

FINAL REPORT: SEPTEMBER 1973 - MAY 1976

AIR FORCE ARMAMENT LABORATORY

AIR FORCE SYSTEMS COMMAND • UNITED STATES AIR FORCE

EGLIN AIR FORCE BASE, FLORIDA

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14

1. ~~REPORT NUMBER~~ AFATL-TR-76-26

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

6

4. ~~TITLE (and Subtitle)~~ AIR FORCE ARMAMENT LABORATORY INFRARED PLUME SIMULATION CAPABILITIES.

9

5. TYPE OF REPORT & PERIOD COVERED: Final Report, Sep[redacted]73 [redacted] May [redacted]76.

6. PERFORMING ORG. REPORT NUMBER

10

7. ~~AUTHOR(s)~~ James F. Long

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Guided Weapons Division (DLMQ)
Air Force Armament Laboratory
Eglin Air Force Base, Florida 32542

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
P.E. 62602F
Proj 19210301

11. CONTROLLING OFFICE NAME AND ADDRESS
Air Force Armament Laboratory
Armament Development and Test Center
Eglin Air Force Base, Florida 32542

11

12. ~~REPORT DATE~~ May [redacted]976

12 64p.

13. ~~NUMBER OF~~ PAGES 65

14. ~~MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)~~

16 AF-1921 17 192103

15. SECURITY CLASS. (of this report) UNCLASSIFIED

15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Distribution limited to U. S. Government agencies only; this report documents test and evaluation; distribution limitation applied May 1976. Other requests for this document must be referred to the Air Force Armament Laboratory (DLMQ), Eglin Air Force Base, Florida 32542.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Available in DDC.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Exhaust Plume
Infrared Radiation
Altitude Simulation
Target Augmentation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Armament Altitude Simulation Facility at the Armament Development and Test Center has been adapted for AFATL experiments and tests to measure infrared radiation properties of target simulator plumes. This document briefly describes the facility and associated instrumentation. It supersedes AFATL-TR-74-15.

dB

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

400936

PREFACE

The infrared plume simulation facilities and instrumentation described in this report were designed and fabricated as a part of Project 19210301, Infrared Simulation Technology, in support of program element 62602F. This is an in-house effort of the Targets Branch (DLMQ) of the Air Force Armament Laboratory (AFATL), Eglin Air Force Base, Florida. Mr James F. Long was the program manager.

The ADTC facility and AFATL experimental apparatus described were assembled over the period 1 September 1973 through 1 May 1976. The capability of this system is limited by the particular equipment installed; therefore, specific models and manufacturers are identified. This does not constitute endorsement of these products by the United States Air Force.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

JOHN W. JOHNSON
Deputy Chief, Guided Weapons Division

(The reverse of this page is blank)

TABLE OF CONTENTS

LIST OF FIGURES

SECTION I

INTPODUCTION

The ADTC Armament Altitude Simulation Facility, located in Building 408, Eglin Air Force Base, Florida, is used to simulate pressure altitude conditions for environmental testing of armament. It is a Technology and Engineering (T&E) facility of ADTC/TG operated and maintained by O&M contract, and entirely dedicated to the Air Force Armament Laboratory (AFATL) for scientific efforts of the Targets Branch (DLMQ).

DLMQ has actively utilized the Armament Altitude Simulation Facility since 1972 as the site for exploratory development and evaluation of in-house and contractor developed infrared plume generators under Project 1921 Task 03. Instrumentation has been developed in-house to measure selected properties of infrared radiators for critical design information relative to Air Force target and missile seeker systems.

This report describes the ADTC Armament Simulation Facility and the capability of AFATL instrumentation used in the facility.

SECTION II

ADTC ARMAMENT ALTITUDE SIMULATION FACILITY

1. SIMULATION CHAMBERS

The ADTC Armament Altitude Simulation Facility consists of three inline chambers which can be pressure controlled from sea level to 60.9-km altitude as a unit or separately. The altitude, concussion and shell-stop chambers were named for earlier purposes of the facility and, although they do not reflect the exact use of the chambers at this time, the names are retained to prevent confusion with architectual drawing and past documentation.

The altitude chamber (Figure 1) is 19 feet 1 inch (5.8 m) long, 11 feet 7 inches (3.5 m) wide, and 11 feet 3 inches (3.4 m) high. It has an end door which opens by chain hoists, permitting the entire end of the chamber to be opened. Within the large door is a smaller door. The chamber has six ports, three on each side, for viewing the interior. The altitude chamber is rarely used for plume studies and is sealed from the adjoining concussion chamber by a calcium flouride window located in the interconnecting tube.

The concussion chamber (Figure 2) is connected to the altitude and shell-stop chambers by a 4-foot 1 inch (1.24-m) steel cylinder in the center at each end. These connecting cylinders can be left open for a line of sight opening between all three chambers or sealed for use as a single chamber. It is in this chamber that infrared plume studies are accomplished by AFATL. The chamber has three 13-inch (33-cm) diameter pipe outlets on top. Two are sealed permanently and the other is a rough vacuum pump line. On the sides and ends of the chamber are seven viewing ports (Figure 3), a 15-inch (38-cm) diameter high-vacuum pump line and an access door 7 feet (2.13 m) wide by 7 feet 8 inches (2.34 m) high. The door is opened and closed by a chain hoist. On the bottom of the chamber there is a sump drain plug. The chamber is cylindrical in shape, 11 feet 8-1/4 inches (3.56 m) in diameter and 19 feet 5 inches (5.9 m) long, with dome-shaped ends adding 2 feet (0.6 m). It is fabricated from 7/8-inch (2.22-cm) welded steel plate.

The shell-stop chamber (Figure 4) is a reinforced concrete chamber designed to withstand the explosive impact of up to a 2-pound (91-gram) explosive charge. This chamber has been sealed from the adjoining concussion chamber and a subsonic air flow system installed permitting ambient air at sea level pressure to be fed into the concussion chamber. This air flow system is described in paragraph 4. The chamber has one door which opens to open air and a window facing the concussion chamber instrumentation room.

2. INSTRUMENTATION ROOM

An environmentally controlled room 18 feet 7 inches (5.66 m) wide, 30 feet (9.14 m) long, and 9 feet 8 inches (2.95 m) high adjoins one side of the concussion chamber for instrumentation and experiment fabrication (Figure 5). The room is air conditioned by two wall units each rated at 2 tons (7.03

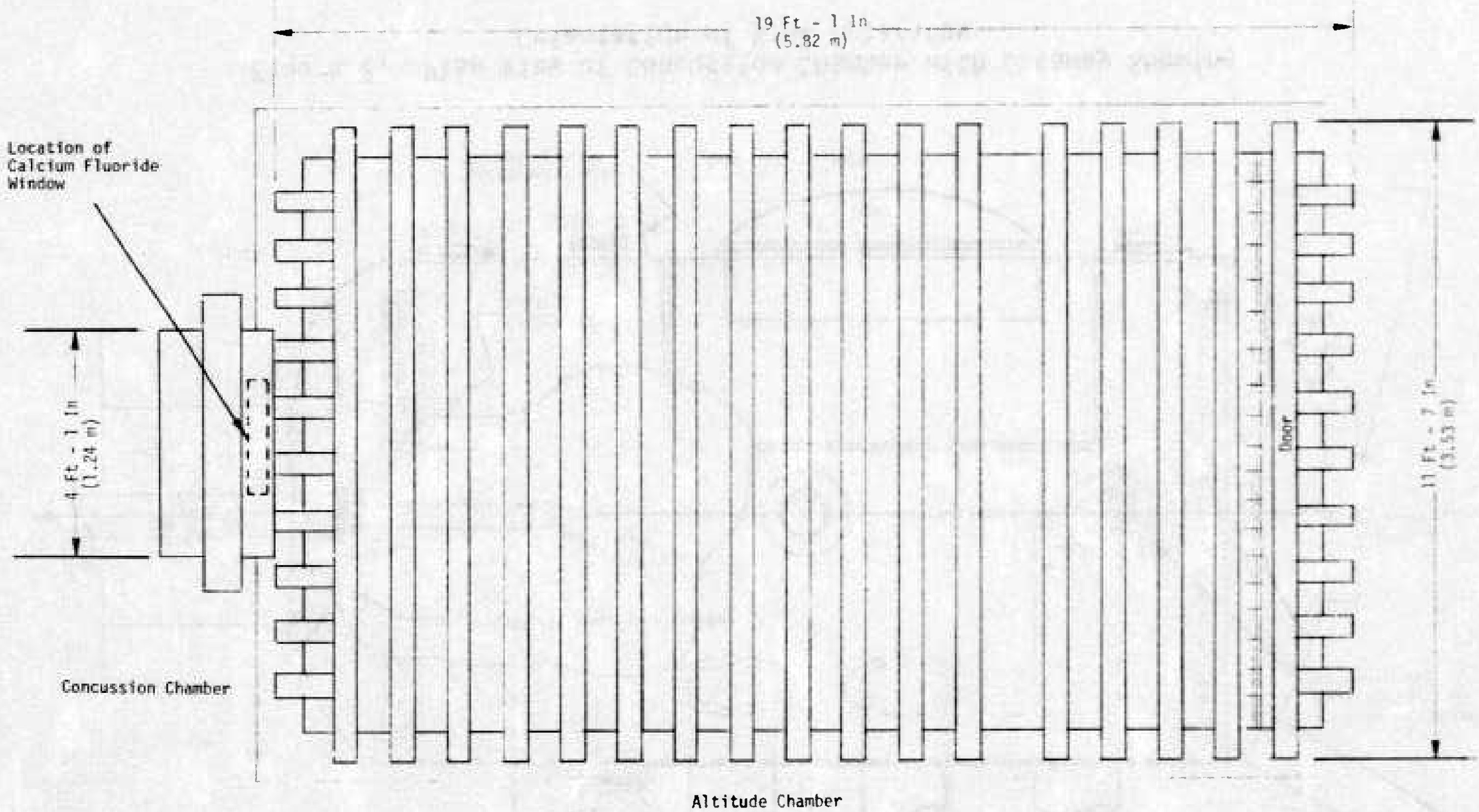


Figure 1. Plan View of Altitude Chamber

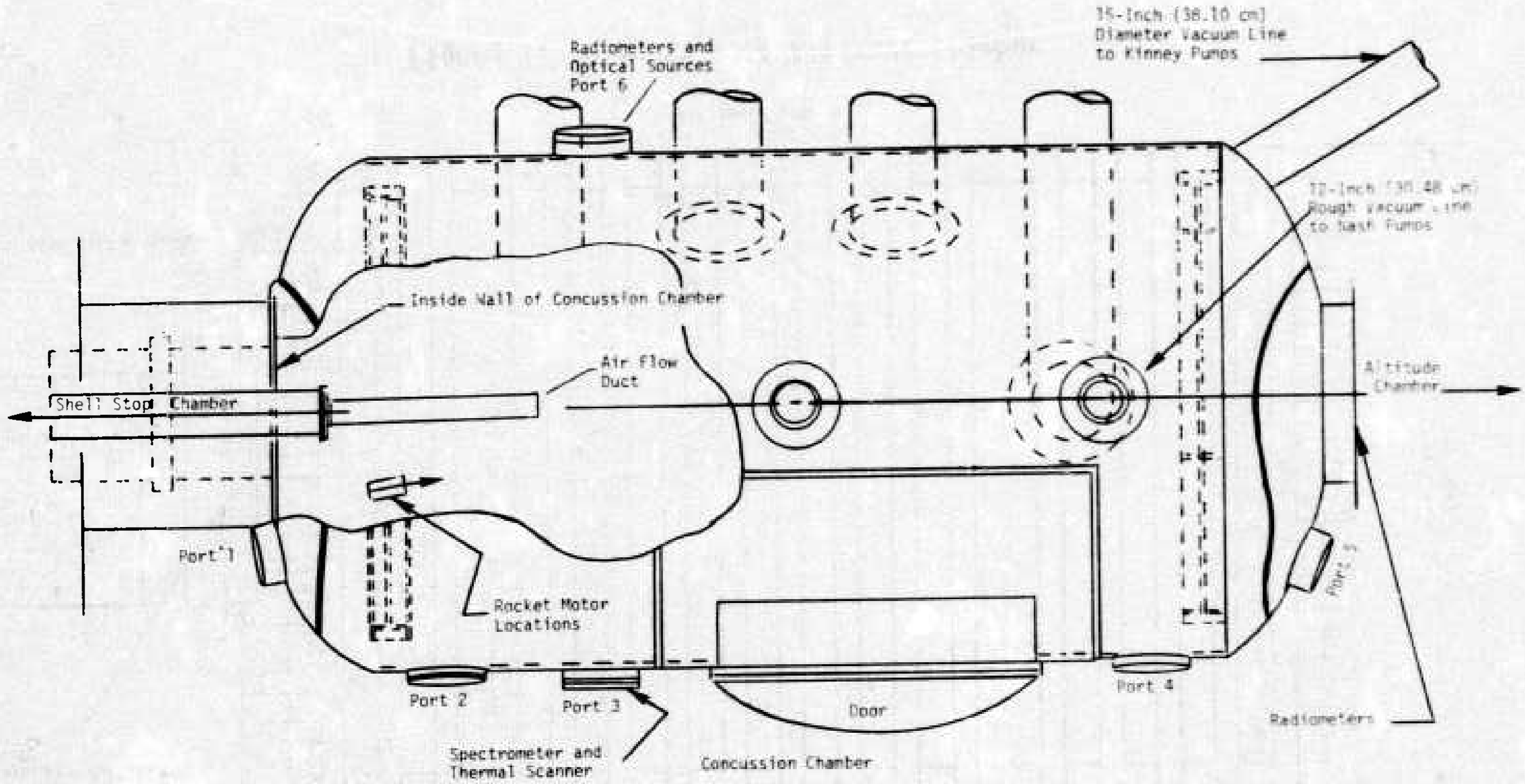


Figure 2. Plan View of Concussion Chamber with Cutaway Showing Orientation of Wind Apparatus

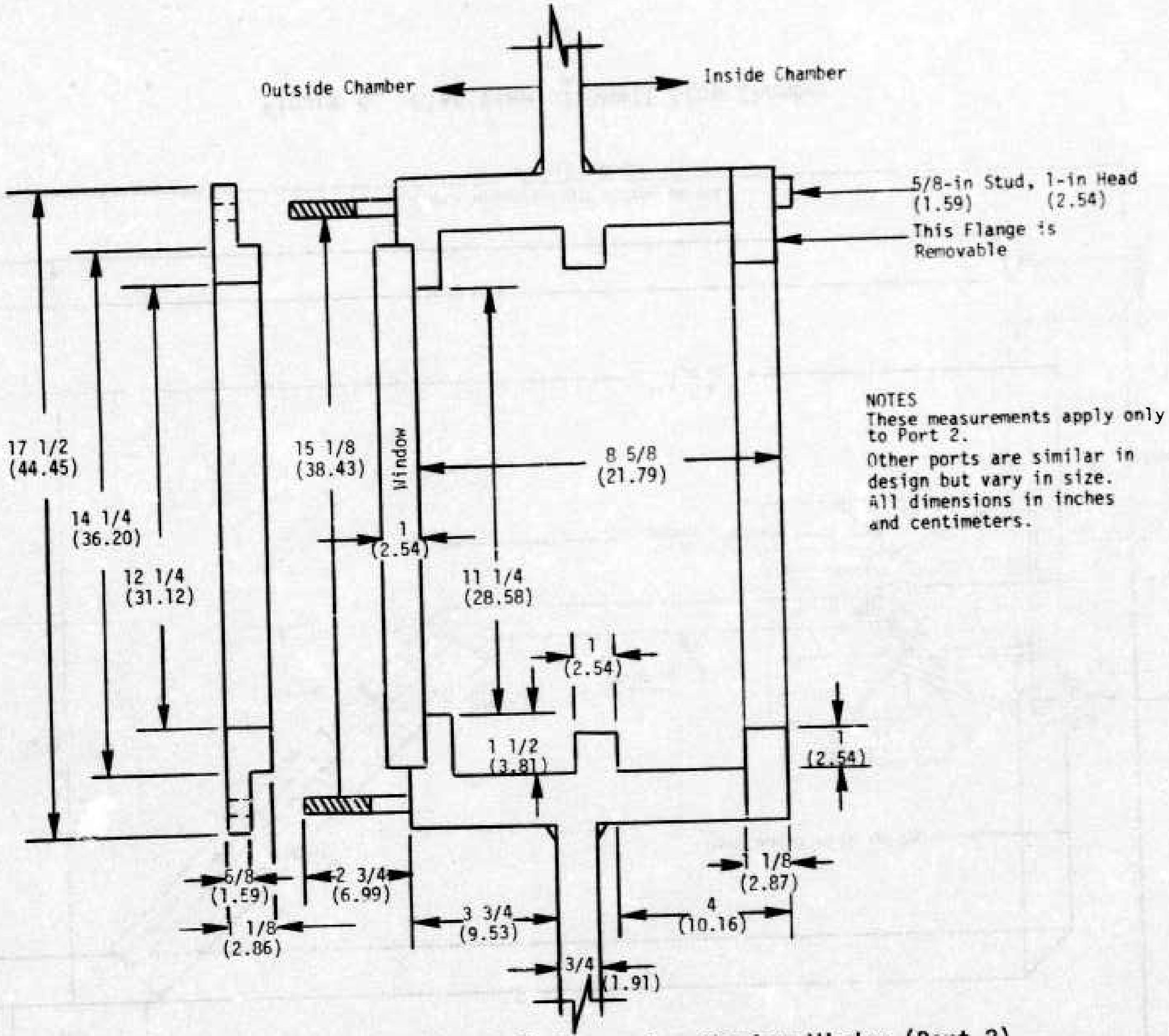


Figure 3. Cross-Section of Typical Concussion Chamber Window (Port 2)

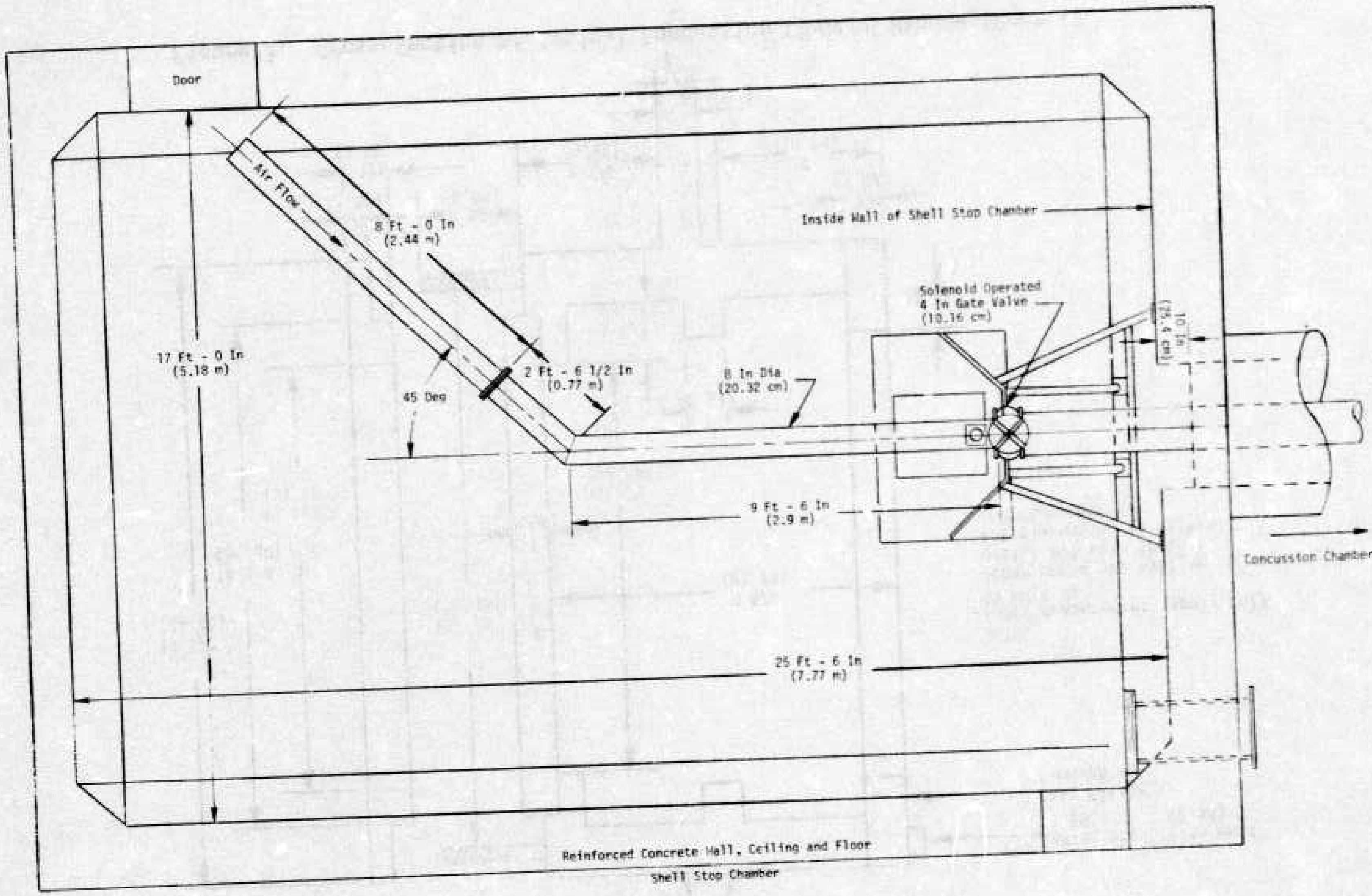


Figure 4. Plan View of Shell Stop Chamber

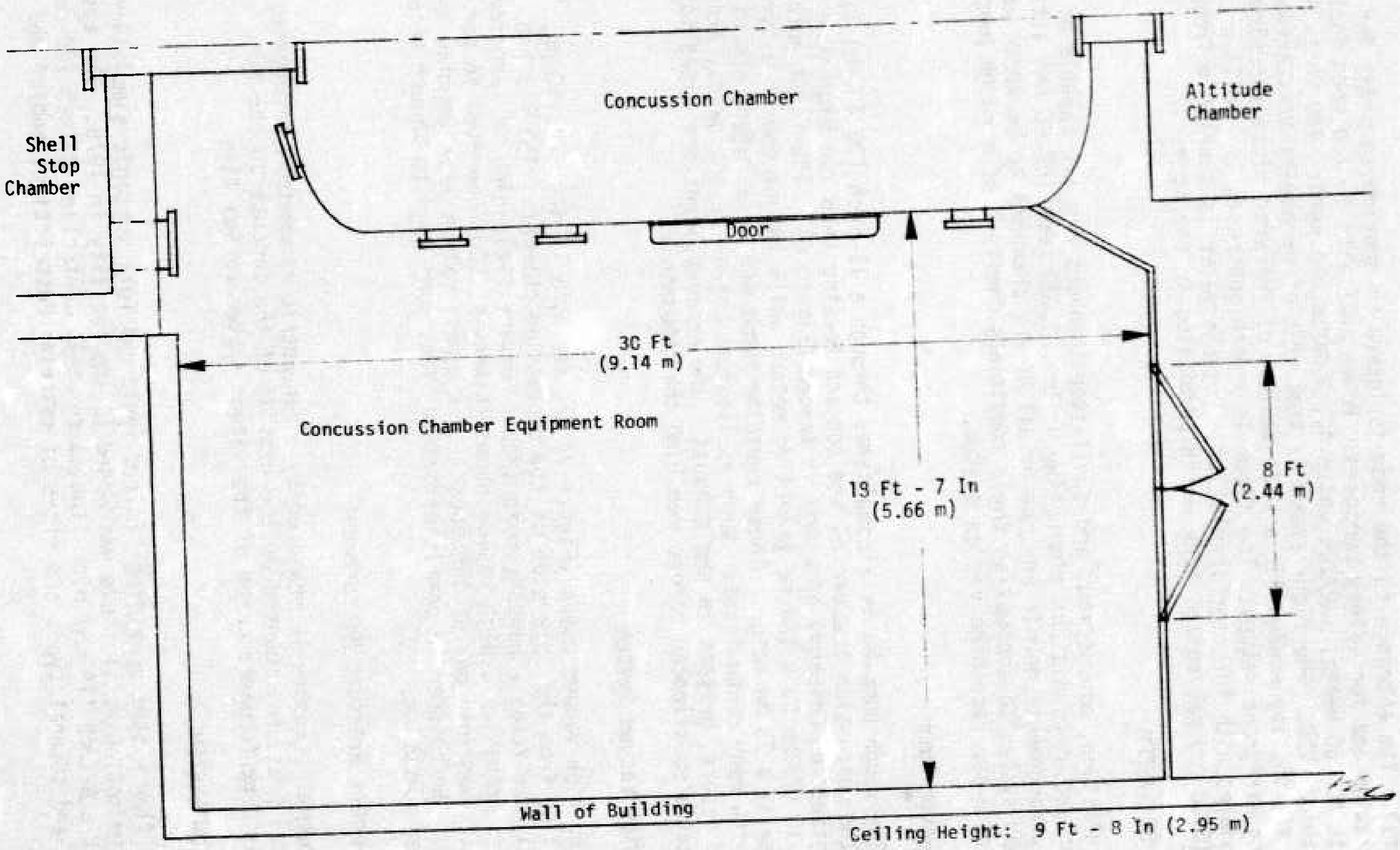


Figure 5. Plan View of Equipment Room

kilowatts). The entrance to the room is locked to provide security for instrumentation and for safety purposes. Power available to the room includes 110 volts AC, 60 hertz; 120/208 volts AC, 3 phase, 60 hertz; 440 volts AC, 60 hertz; and 28 VDC. The floor space is kept free of permanent structures to provide flexibility needed for a wide variety of infrared plume experiments requiring different setups. The floor is smooth concrete, the walls are thin steel modules with interior insulation. Potable water is available from a 2-inch (5.08-cm) galvanized pipe which terminates in the room.

3. VACUUM SYSTEM

The altitude, concussion, and shell-stop chambers are all capable of achieving vacuum conditions simulating up to 200,000 feet (60.96 km) altitude. Valving arrangements permit any one or all of the chambers to be under vacuum. The vacuum system to accomplish these conditions consists of a rough pumping system and a separate high vacuum system.

a. Rough Pump

The rough pumping is accomplished through a 12-inch (30.48-cm) line leaving the concussion chamber at the top and feeding into two high torr pumps (Nash Engineering Company) operated in tandem (Figure 6). The first pump is a type L-10 driven by a 150 hp induction motor, while the second is a type H-9 driven by a 75 hp motor. These roughing pumps are very rugged and will operate with many contaminants, such as liquids, corrosive hot gases, and saturated vapors, present in the exhaust. The exhaust gases are piped into a water-actuated silencer before reaching the atmosphere.

b. High Vacuum System

The high vacuum pumps (Figure 7) are fed by a 15-inch (38.10-cm) diameter line from the back side of the concussion chamber. The 15-inch (38.10-cm) line feeds a booster pump (Roots-Connerville) which in turn feeds two triplex mechanical, high vacuum pumps (Kinney KT 500) operated in parallel from an exit manifold out of the booster. A bypass valved line permits operation around the booster to permit efficient, fast pump-down to vacuum necessary for booster operation.

c. Chamber Pressure Measurement

Chamber pressure is measured by a barometric manometer, referenced to sea level pressure, mounted on the outside of the concussion chamber. Figure 8 is a performance curve of the vacuum system versus time.

4. AIR FLOW SYSTEM

An air flow system providing limited sonic and full subsonic simulation of test item motion at altitude was added to the facility in 1975. The system consists of a 6-inch (15-cm) pipe line, a remotely controlled 8-inch (20-cm) gate valve and several types and sizes of metering restrictions and/or end

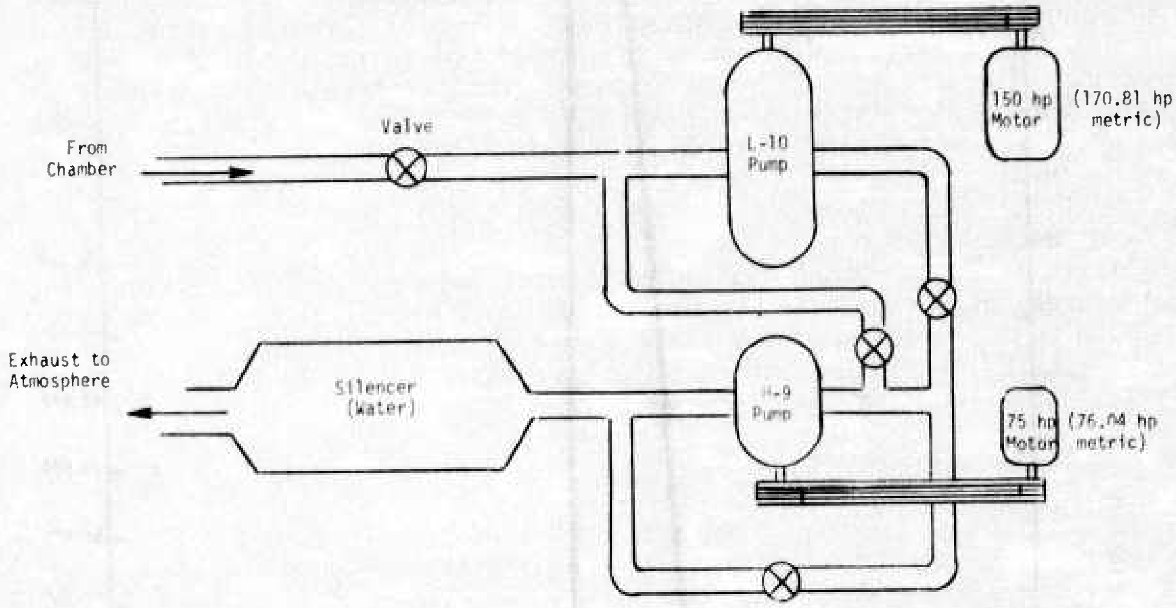


Figure 6. Roughing Vacuum Pump System

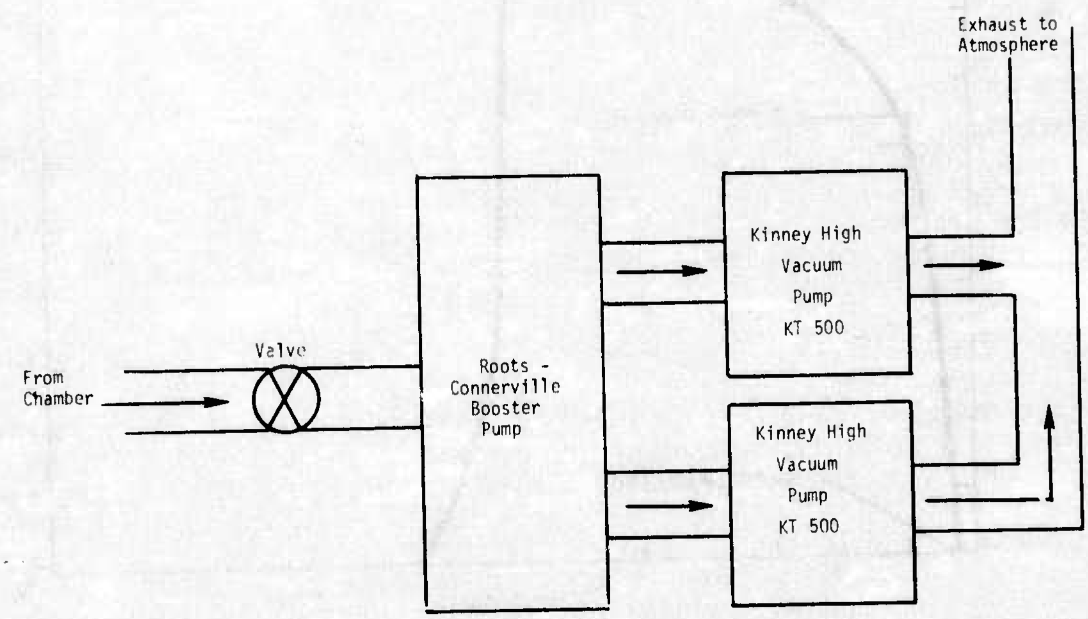


Figure 7. High Vacuum Pumping System

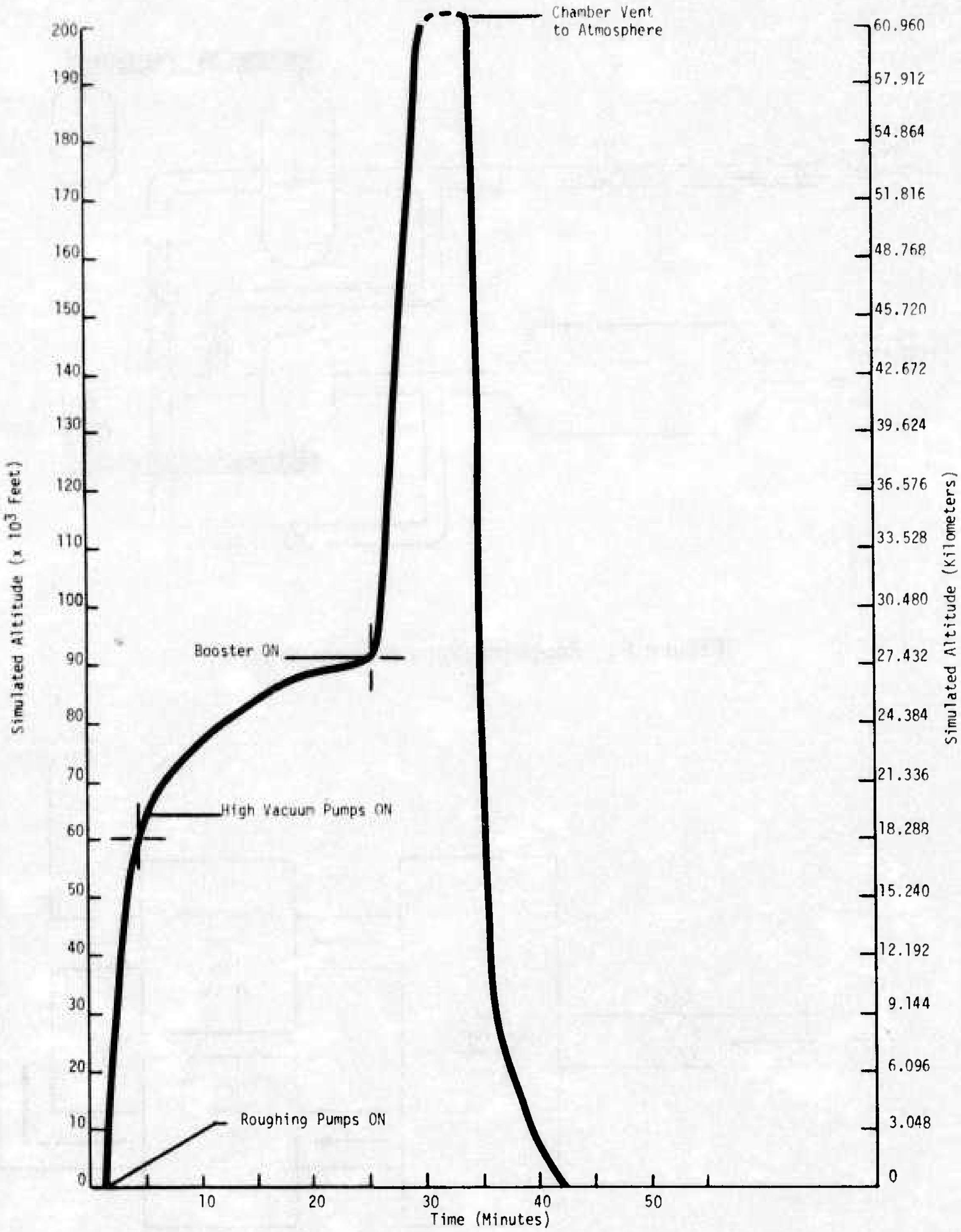


Figure 8. Performance of Vacuum System for Concussion Chamber

plate chokes. By opening the gate valve, sea level air is permitted to flow into the chamber. By selection of metering restrictions or end plate chokes, the air flowing over the test item can be regulated to simulate various velocities. Typical profiles of the flow field are described in Figures 9 and 10. A wide variety of chokes designed for supersonic and subsonic conditions at different altitudes and Mach numbers are available. Chokes can be designed and built at AFATL for almost any flow condition desired.

The Schlieren system described in Section IV is used to observe the flow pattern of this air flow system.

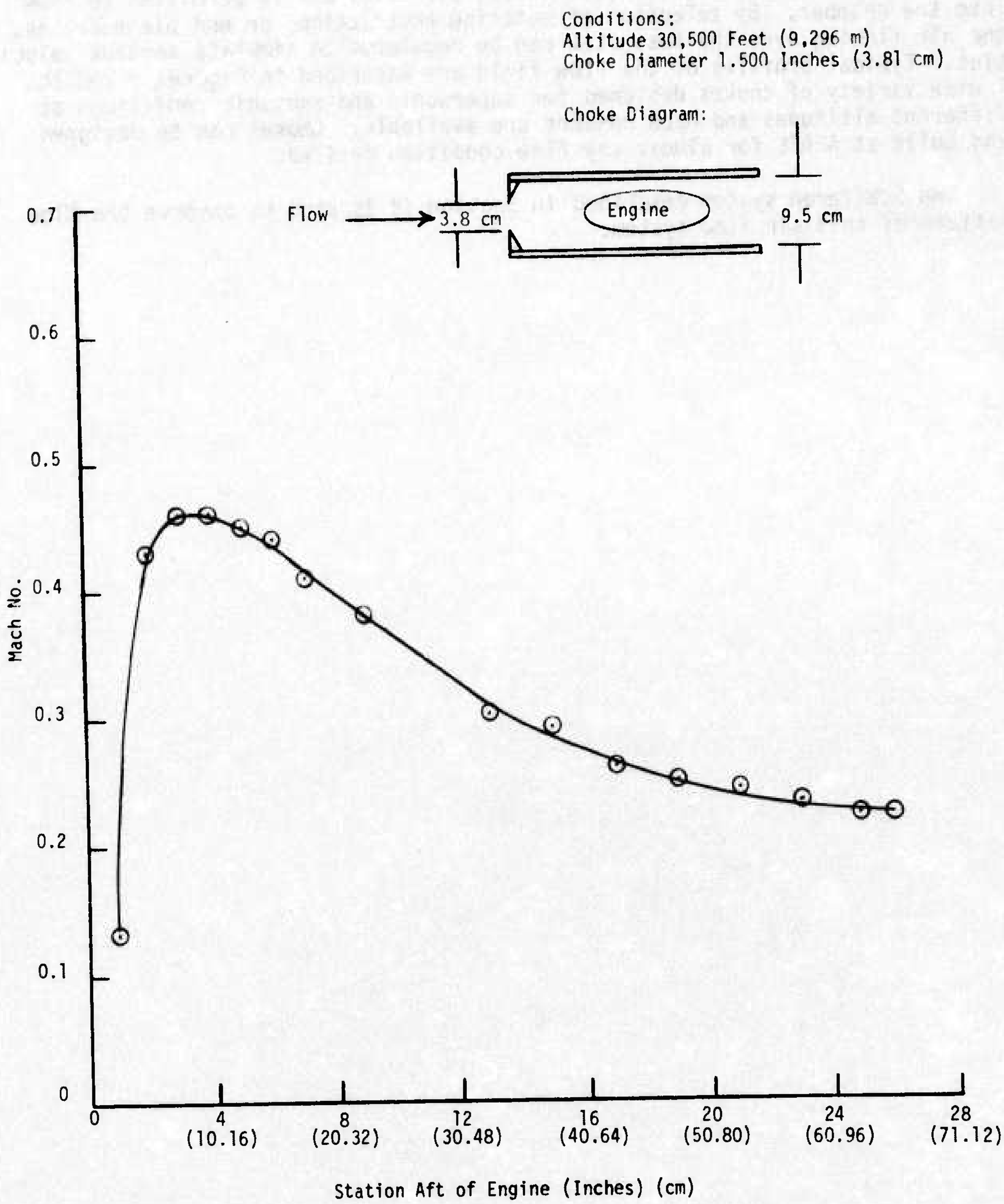


Figure 9. Typical Profile of Air Flow

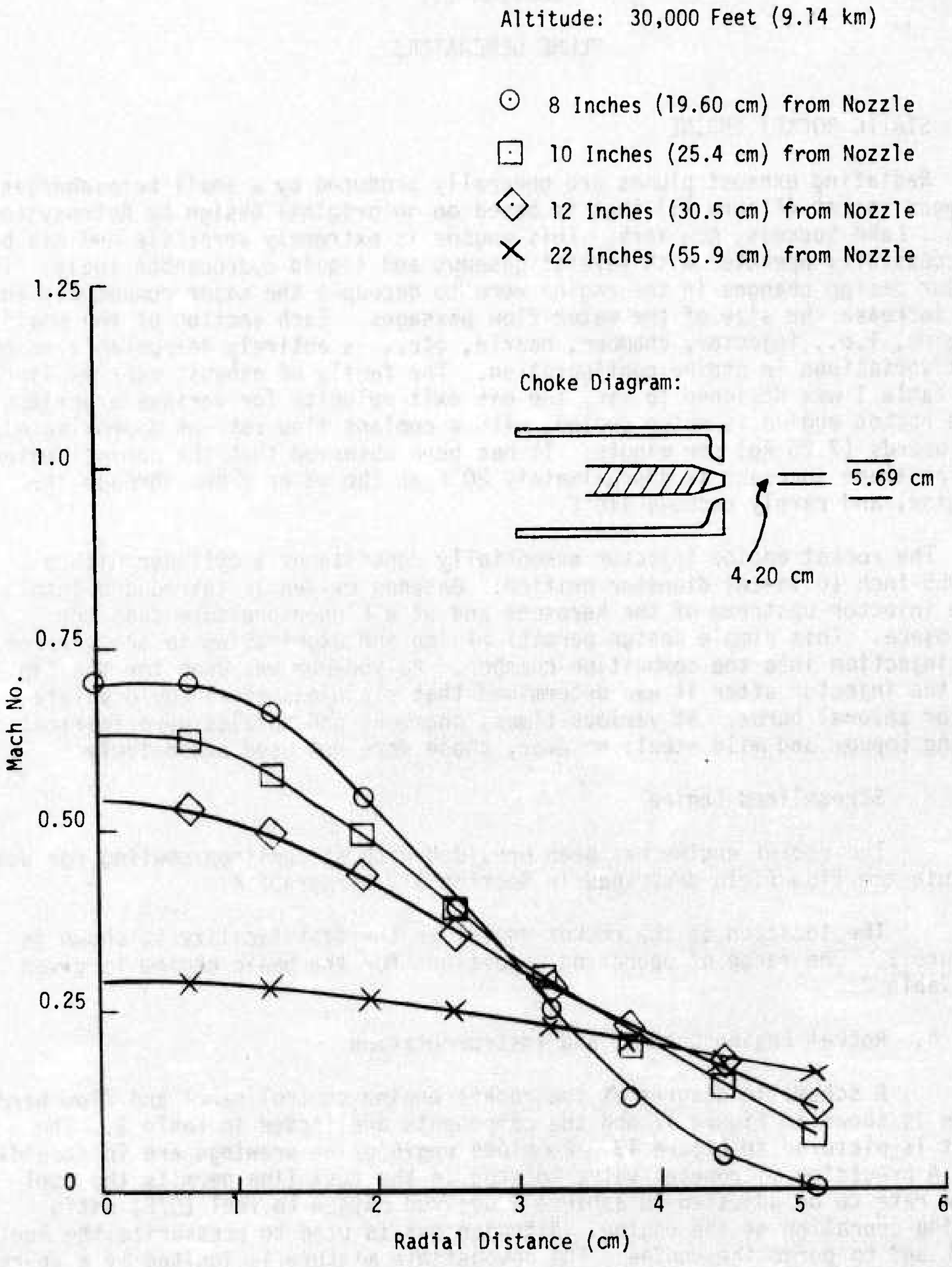


Figure 10. Typical Profile of Air Flow (for HAST Simulation)

SECTION III

PLUME GENERATORS

1. STATIC ROCKET ENGINE

Radiating exhaust plumes are generally produced by a small kerosene/gaseous oxygen rocket (Figure 11) that is based on an original design by Astrosystems, Inc., Lake Success, New York. This engine is extremely versatile and has been successfully operated with several gaseous and liquid hydrocarbon fuels. The major design changes in the engine were to decouple the major components and to increase the size of the water flow passages. Each section of the modified engine, i.e., injector, chamber, nozzle, etc., is entirely demountable to permit variations in engine configuration. The family of exhaust nozzles listed in Table 1 was designed to vary the gas exit velocity for various experiments. The rocket engine is water cooled, with a coolant flow rate of approximately 16 pounds (7.26 kg) per minute. It has been observed that the nominal water temperature increase is approximately 20°F as the water flows through the engine, and rarely exceeds 110°F.

The rocket engine injector essentially consists of a cylinder with a 0.055-inch (0.14-cm) diameter orifice. Gaseous oxygen is introduced into the injector upstream of the kerosene and at a higher pressure than the kerosene. This simple design permits mixing and atomization to occur prior to injection into the combustion chamber. Molybdenum was used for the tip of the injector after it was determined that stainless steel would ablate after several burns. At various times, chambers and nozzles were fabricated using copper and mild steel; however, these were not used extensively.

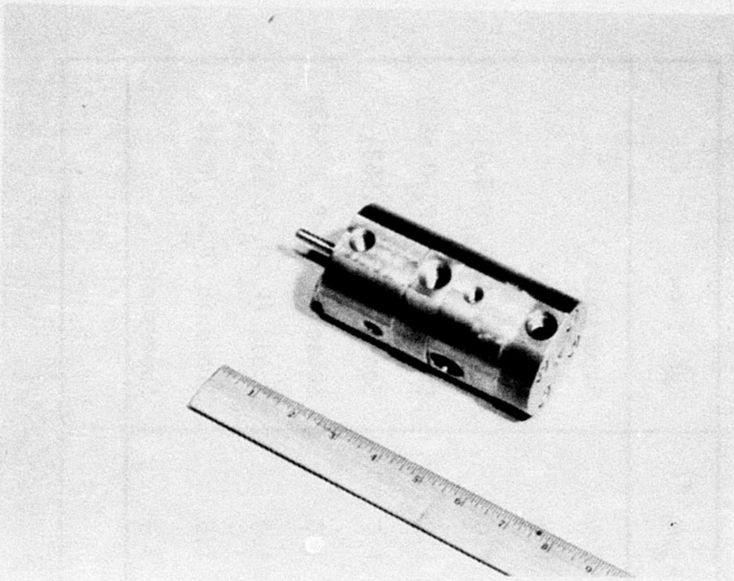
a. Streamlined Engine

The rocket engine has been provided with streamlined cowling for use within the flow field described in Section II, paragraph 4.

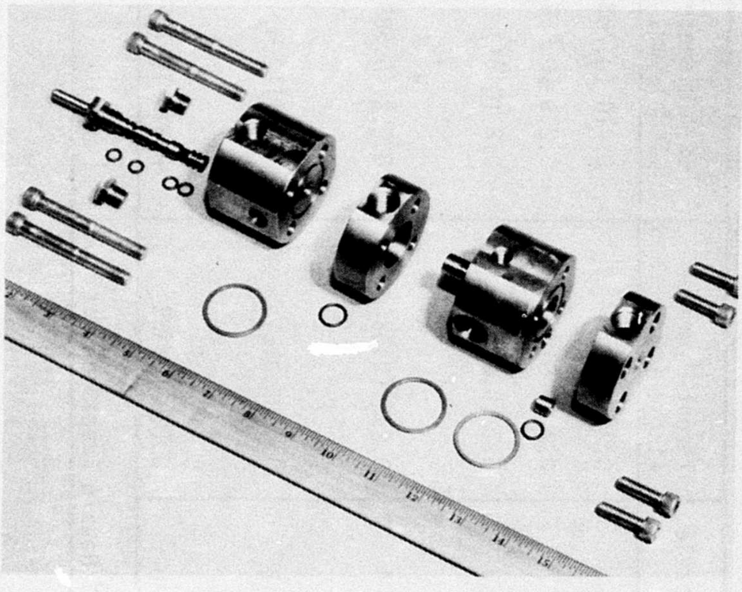
The location of the rocket engine in the test facility is shown in Figure 2. The range of operating conditions for the basic engine is given in Table 2.

b. Rocket Engine Control and Instrumentation

A schematic diagram of the rocket engine control panel and flow hardware is shown in Figure 12 and the components are listed in Table 3. The unit is pictured in Figure 13. Complete engineering drawings are in Appendix A. A precision micrometer valve located in the fuel line permits the fuel flow rate to be adjusted to achieve a desired oxygen to fuel (O/F) ratio during operation of the engine. Nitrogen gas is used to pressurize the fuel tank and to purge the engine. The combustible mixture is ignited by a spark plug (Autolite A-5 or equivalent) driven by an auto ignition coil.



(a) Engine Assembled



(b) Engine Disassembled

Figure 11. Static Rocket Engine

TABLE 1. DIMENSIONS OF EXHAUST NOZZLES

Nozzle	Throat Diameter (Inch) (cm)	Exit Diameter (Inch) (cm)	A_e/A_T [a]	Type Flow
1	0.2 (0.51)	0.310 (0.787)	2.4	Supersonic
2	0.2 (0.51)	0.219 (0.556)	1.2	Supersonic
3	0.2 (0.51)	0.2 (0.51)	1.0	Sonic ($P_C > P_A/0.553$)
			1.0	Subsonic ($P_C < P_A/0.553$)
4	0.232 (0.589)	0.232 (0.589)	1.0	Sonic ($P_C > P_A/0.553$)
			1.0	Subsonic ($P_C < P_A/0.553$)
5	0.4 (1.016)	0.4 (1.016)	1.0	Sonic ($P_C > P_A/0.553$)
			1.0	Subsonic ($P_C < P_A/0.553$)
6	0.128 (0.325)	0.310 (0.787)	5.9	Supersonic

[a] Nozzle Expansion Ratio

TABLE 2. ROCKET ENGINE OPERATION CONDITIONS

Engine Nozzle	Mass Flow Rate (Gm/Sec)	Chamber Pressure (Psia)	Oxidizer/ Fuel Ratio	Altitude
0.2-in throat (0.51 cm)	3 to 10	10 to 200 (0.68 to 13.6 atm)	0.8 to 6.0	Sea level to 60,000 feet (18.29 km)
0.4-in throat (1.02 cm)	7 to 12	4 to 30 (0.28 to 2.10 atm)	1.0 to 6.0	Sea level to 60,000 feet (18.29 km)

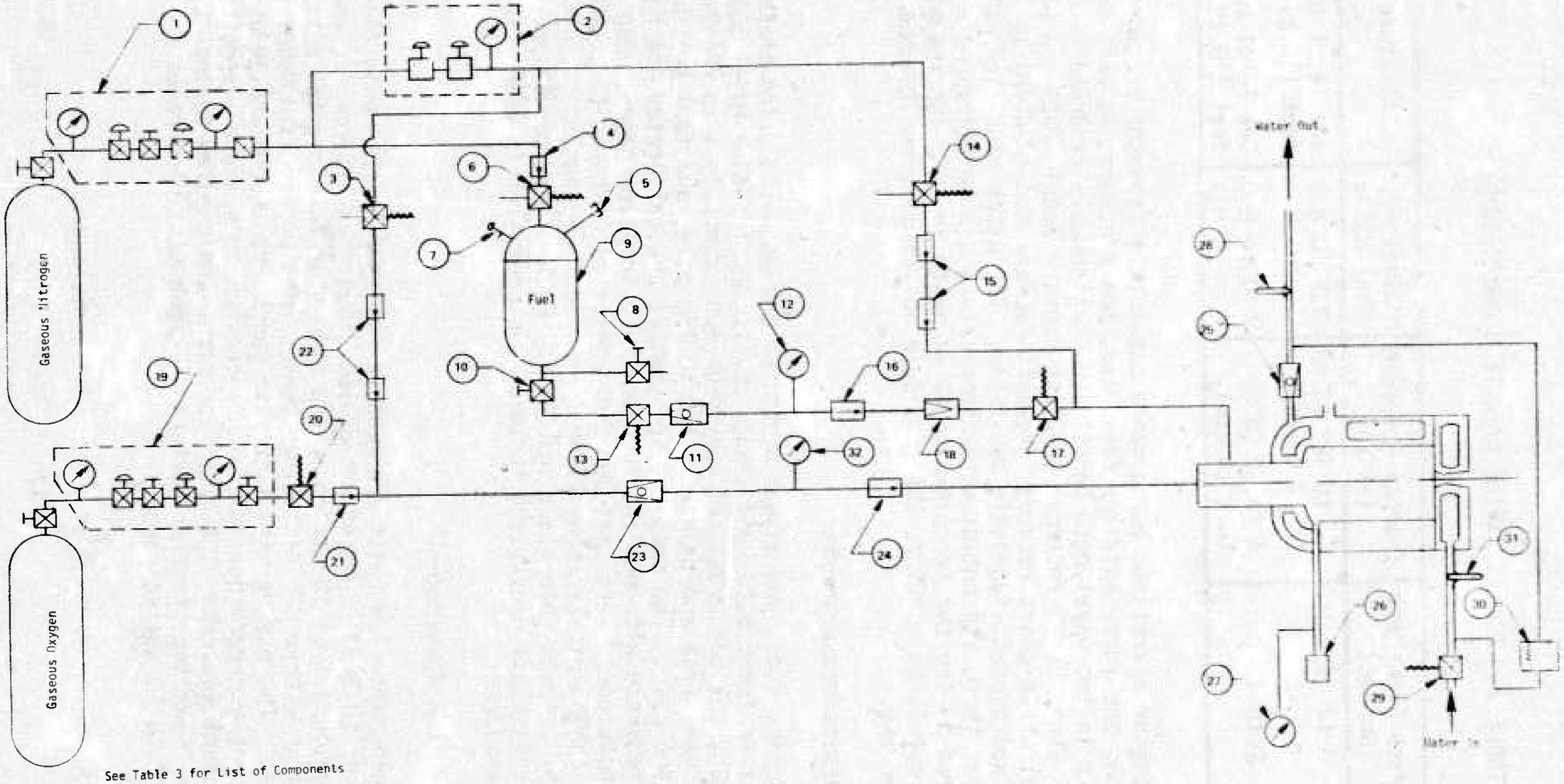
During engine operation, performance parameters (chamber pressure, fuel flow rate and pressure, oxidizer flow rate, and pressure, as well as radiant intensity in two wavelength bands) are continuously recorded using an eight-channel strip chart recorder (Hewlett-Packard Model 7700). A second, four-channel strip chart recorder (Hewlett-Packard Model 7414A) is used to monitor additional diagnostic variables. The water mass flow rate, inlet water temperature, and outlet water temperature can be displayed and visually monitored during the tests to ensure adequate cooling for the engine. Closed circuit television monitors are available to visually monitor the experiments under way.

(1) Pressure Measurements

Chamber, fuel, and oxygen pressures are measured using pressure transducers (Kistler Model 606A) and charge amplifiers (Kistler Model 504D). During experiments, chamber pressures vary from approximately 4 to 200 psia, oxygen pressures vary from approximately 100 to 450 psig, and fuel pressures vary from 80 to 400 psig. The pressure transducers are calibrated and frequently cross-referenced with helicoid Bourdon tube pressure gages. Eight analog signal conditioners were designed and fabricated in-house to provide analog/analog or analog/digital conversion for various diagnostic gas dynamics or infrared sensor outputs into exact cgs units. Each signal conditioner provides for an adjustable conversion factor. One condition is used with each pressure transducer.

(2) Mass Flow Measurement

Oxygen mass flow rates are measured using a thermal mass flowmeter (Brooks Model 5812-3). One of the analog signal conditioners converts the analog voltage output of the thermal mass flowmeter to a digital voltage that is displayed on a true RMS digital voltmeter (Hewlett-Packard Model 3404) directly in gm/sec. The oxygen mass flow rate can be monitored and adjusted to within ± 5 percent accuracy during engine operation to achieve a specified O/F value. To assure accuracy, the mass flow rates are checked against a glass tube oxygen flowmeter (Fischer-Porter) Oxygen mass flow rates are typically in the 2 to 10 gm/sec range.



See Table 3 for List of Components

Figure 12. Engine Control Panel Schematic

TABLE 3. ROCKET ENGINE CONTROL PANEL COMPONENT IDENTIFICATION

Item No.	Description
1	Pressure Regulator - Fuel Pressure
2	Pressure Regulator - Purge
3	Purge Valve, Ox Line, 3-Way, 1/4 inch (0.64 cm)
4	Check Valve, Fuel Pressurizing Line
5	Fill Cap, Fuel Tank
6	Pressurizing and Vent Valve, Fuel Tank, 3-Way, 1/4 inch (0.64 cm)
7	Burst Diaphragm, Fuel Tank, 500 psig (34 atm)
8	Fuel Tank Drain Valve (Manual)
9	Fuel Tank, 2.0 Gallon Capacity (7.51 liters)
10	Fuel Tank Outlet Valve (Manual)
11	Flowmeter (1/4 to 1/4 Flat)
12	Pressure Gage, Fuel Inlet (0 to 400 psig) (0 to 27.22 atm)
13	Safety Valve, Fuel
14	Purge Valve, Fuel Line, 3-Way, 1/4 inch (0.64 cm)
15	Check Valve, Fuel Purge Line
16	Check Valve, Fuel Line
17	Propellant Control Valve, Fuel
18	Filter, Fuel Line (25 microns)
19	Pressure Regulator, Oxygen
20	Control Valve, Oxygen 1/4 inch (0.64 cm)
21	Check Valve, Oxygen Supply Line
22	Check Valve, Oxygen Line Purge
23	Flowmeter, Oxygen 3/4 to 1/2 inch (1.91 to 1.27 cm)
24	Check Valve, Oxygen Supply Line
25	Flowmeter, Coolant 3/4 to 3/4 inch (1.91 to 1.91 cm)
26	Pressure Switch
27	Pressure Gage, 0 to 200 psig (0 to 13.6 atm)
28	Thermometer 0 to 200 degrees, 2-degree Sub Div, 6-inch (15.24 cm) Stem
29	Solenoid Valve
30	Differential Pressure Switch, 3 psi Differential
31	Thermometer, 0 to 200°F, 2-degree Sub Div, 6-inch (15.24 cm) Stem
32	Pressure Gage, Oxygen Line

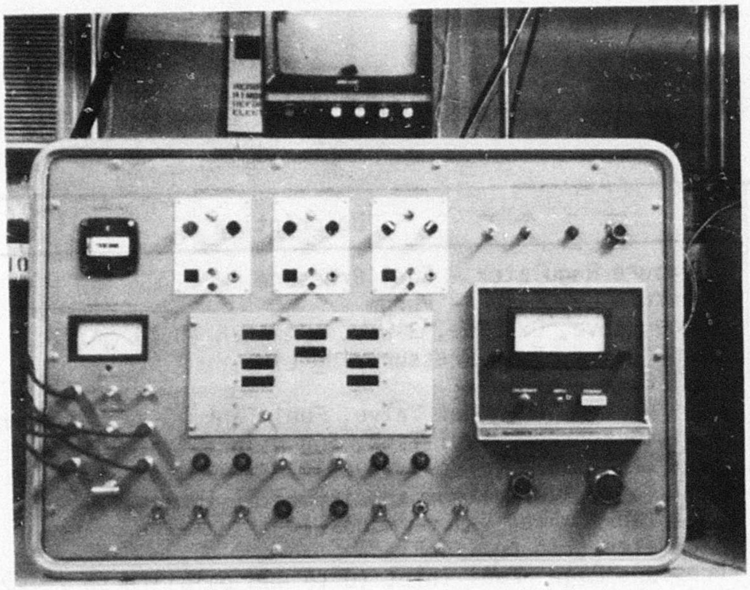


Figure 13. Engine Control and Monitoring Console

Fuel flow rates are measured using a turbine flowmeter (Brooks Model 4904) that is calibrated and compared with a glass tube fuel flowmeter (Fischer-Porter). An analog signal conditioner is used to convert the analog voltage directly into gm/sec in the same manner as for the oxygen flow rate. This voltage is recorded and displayed on the digital voltmeter via a coaxial switch that can be switched to either the oxygen flow rate or the fuel flow rate. Typically, kerosene flow rates have varied from 0.2 to 4 gm/sec. The fuel flow rate, and thus the O/F ratio, can be closely set by observing the digital voltmeter while adjusting the micrometer valve in the fuel line.

c. Rocket Engine Portability

The entire rocket engine and control console have been modified to permit maximum portability to other field locations. The control package consists of two units. The control unit is housed in a 35-1/2x24-1/2x23-1/4-inch (90.17x62.23x59.06-cm) metal container, weighing 50 pounds, and a valve unit is housed in a 26x28x34-inch (66.04x71.12x86.36-cm) metal container weighing 25 pounds.

2. SOLID ROCKET MOTORS

The ADTC facility is capable of limited testing using solid rocket motors. The concussion chamber is licensed by Eglin Explosive Safety to operate solid rocket motors with fuel grains of up to 2 pounds (908 grams) of propellant Class 2, Storage Category B, material. All propellants are controlled and stored by the 3207th Munitions Maintenance Squadron (LGMM). Operations of LGMM are defined and governed by AFM 1270100 and ADTCR 136-1.

ADTCR 136-1 Technical Data Requirements must be provided to LGMM on the propellant formulation and igniter squib at least 30 days prior to receipt of solid rockets at Eglin Air Force Base, Florida.

SECTION IV

AIR FORCE ARMAMENT LABORATORY INSTRUMENTATION

Plume studies require a wide array of infrared and optical instrumentation and diagnostic equipment. The following are available at the facility:

(a) Infrared radiometers

(b) Spatial scanning infrared camera

(c) Interferometer spectrometer

(d) Visible grating spectrometer

(e) Schlieren system

(f) Motion picture cameras (visible)

(g) Closed circuit TV camera.

1. INFRARED RADIOMETERS

Two radiant flux meters (Hewlett-Packard Model 8330A) are used with 64 element thermopile radiant flux detectors (Hewlett-Packard Model 8334A) to measure irradiance from 3 microwatts to 100 mW/cm^2 in 10 overlapping ranges. The measured field of view for these radiometers is shown in Figure 14. The window material in one detector is quartz while the other is calcium fluoride. The radiant flux (total watts) and radiance (watts/cm^2) are simultaneously displayed on the front panel of the meter. The Model 8330A instrumentation uncertainty is ± 1 percent of full scale. A front panel switch can be used to compensate for different probe efficiencies.

This instrument is equipped for internal zeroing of the range in use and for internal calibration in the 3 mW/cm^2 range. An output is provided for recorder or digital voltmeter readout.

A single black-surface leaf shutter which is actuated remotely from the control panel site, has been placed in front of the detectors. This shutter permits zeroing of the radiometers against an ambient temperature background at any time. The simple shutter mechanism is necessary when the instrument is operated in the five lower ranges. Large errors can otherwise be accumulated due to thermal drift in the detectors. Radiometer data points are generally marked on the strip-chart recorders following a sequence of shutter closing, detector zeroing, and shutter opening. The two radiometers are located at various ports around the concussion chamber and view the rocket exhaust through 5.5-inch (14-cm) diameter calcium fluoride windows.

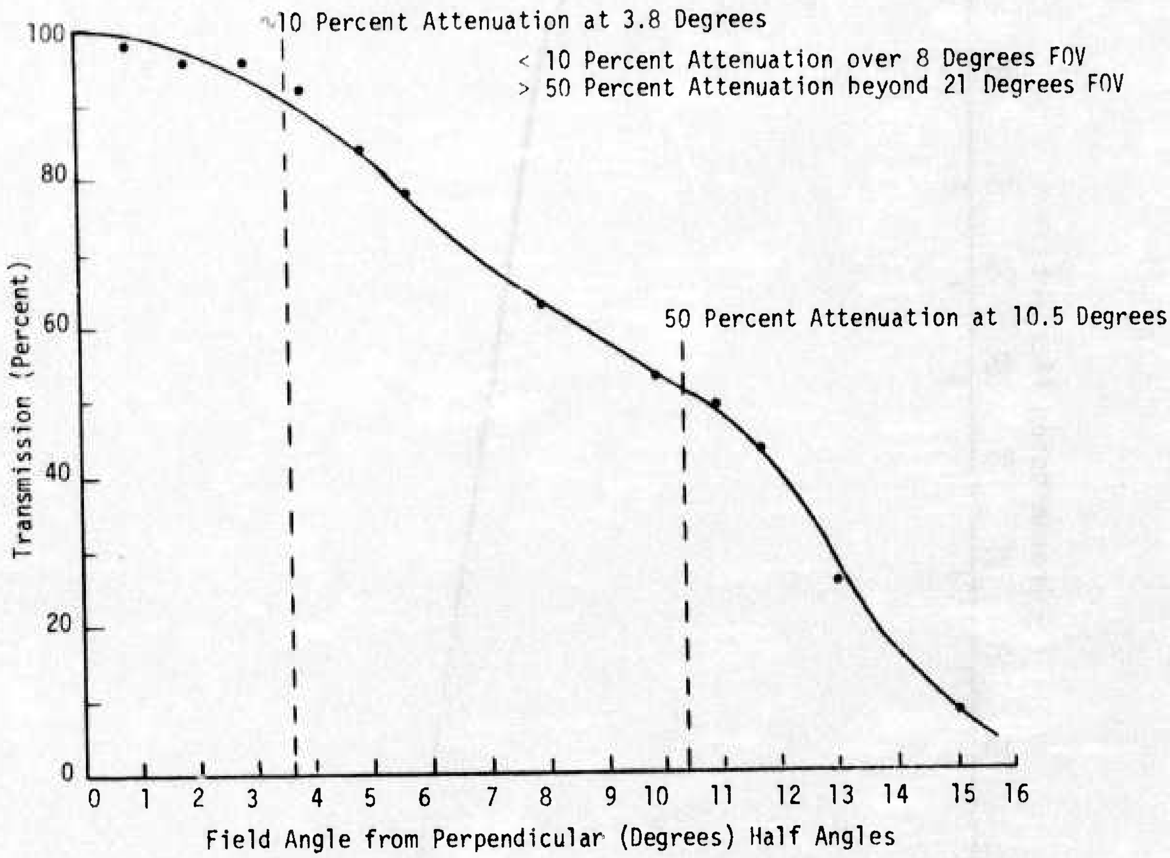


Figure 14. HP 8330A Radiometer Field of View

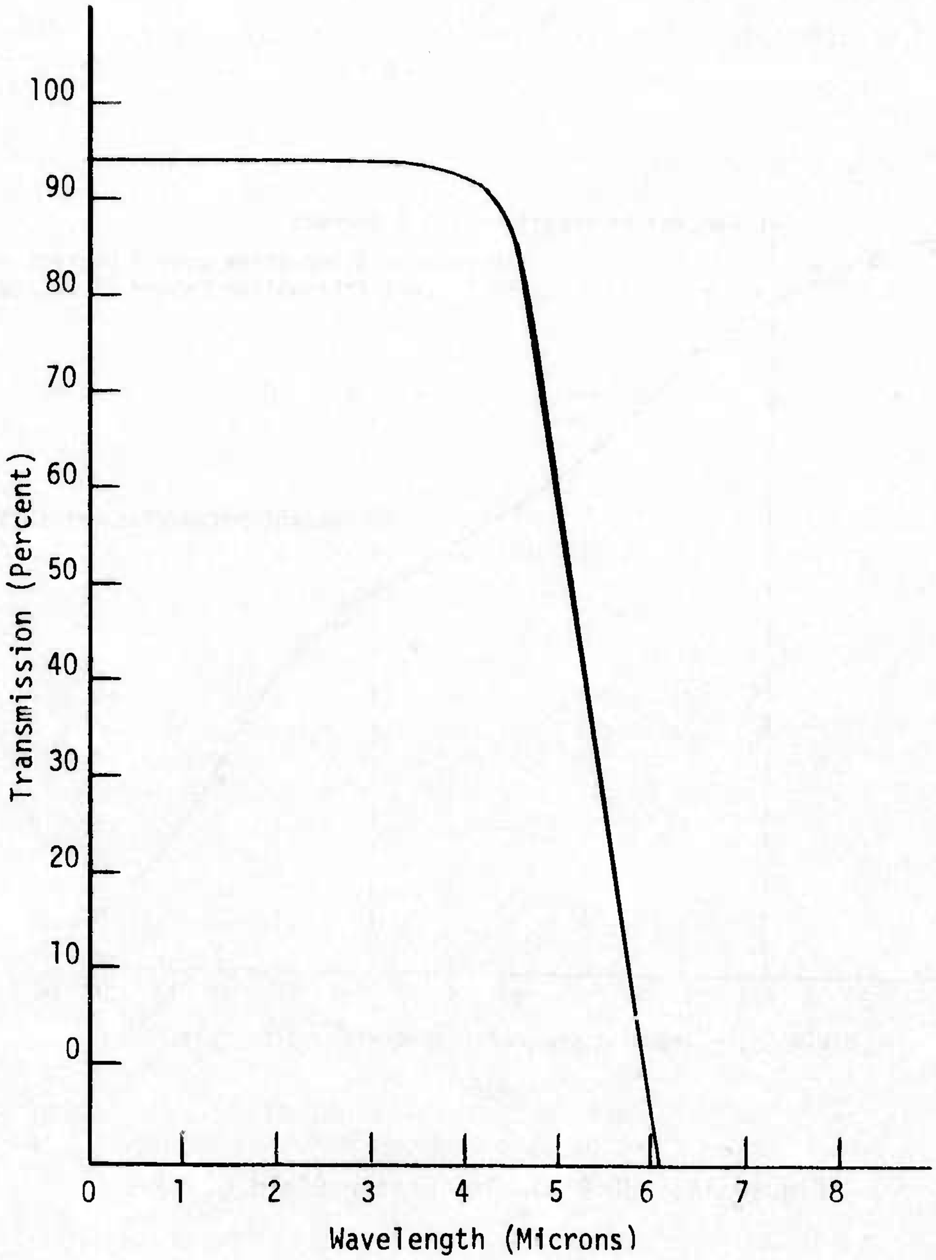


Figure 15. Sapphire Window Transmission Curve (On Chamber)

2. SPATIAL SCANNING INFRARED CAMERA

A real-time optical/mechanical scanning AGA thermovision Model 680/102B system (Figure 16) is a part of AFATL instrumentation. (See Appendix D for specification sheet.)

The AGA system is provided with a digitized output and tape recorder permitting data to be collected and analyzed by the CDC 6600 computer system at Eglin Air Force Base.

3. INFRARED INTERFEROMETER SPECTROMETER

A Block Inc., Model 197, infrared Fourier transform interferometer spectrometer system (Figure 17) is used to measure the spectral distribution of the radiating plume. The interferometer uses a HeNe laser reference and various cooled or uncooled detectors for covering the spectral region from 2 through 14 microns. A built-in mini-computer is preprogrammed to control key operational, measurement, and calibration parameters, and signal averages, to calculate the Fourier transform, and to plot the spectrum on an integral x-y plotter.

The maximum resolution is 2 cm^{-1}. The transform computation time is approximately 5 seconds, so the total time from the spectral sample to the end of the spectrum plot can be less than 1 minute. The spectrometer output as a function of wavelength is spectral irradiance or apparent radiant spectral intensity per unit wavelength. A calibrated blackbody with a maximum temperature of 1000°C is required for quantitative data reduction. A typical spectrum is given in Figure 3.

4. CZERNY-TURNER SPECTROMETER

A Jarrell-Ash Model 78-490, one meter, two mirror Czerny-Turner spectrometer/spectrograph (Figure 18) is utilized to operate in the visible or near infrared dependent on the grating selected. Two Bausch and Lomb gratings are available. One is a 102x102-mm, 1180 grooves/millimeter, grating blazed for 5000 angstroms providing an effective aperature of f/8.7. The other grating is of the same size except it is 590 grooves/millimeter blazed for 7500 angstroms.

A Princeton Applied Research Corporation Model 1205A optical multi-channel analyzer (OMA) with a standard silicon vidicon detector, has been adapted to the exit aperature of the spectrometer making it an effective spectrograph having the ability to digitize the signal and background and process these two to enhance signals. The signals can be plotted by x-y plotters or recorded on tape for later assessment.

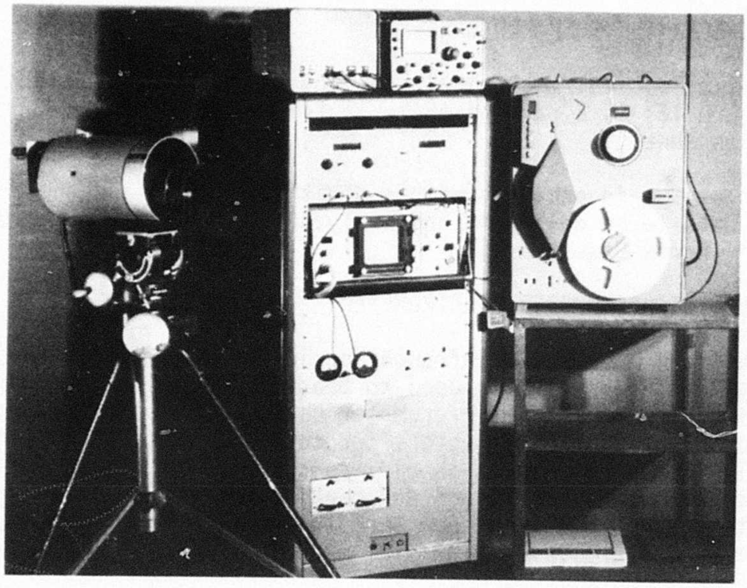


Figure 16. Spatial Scanning Infrared Camera

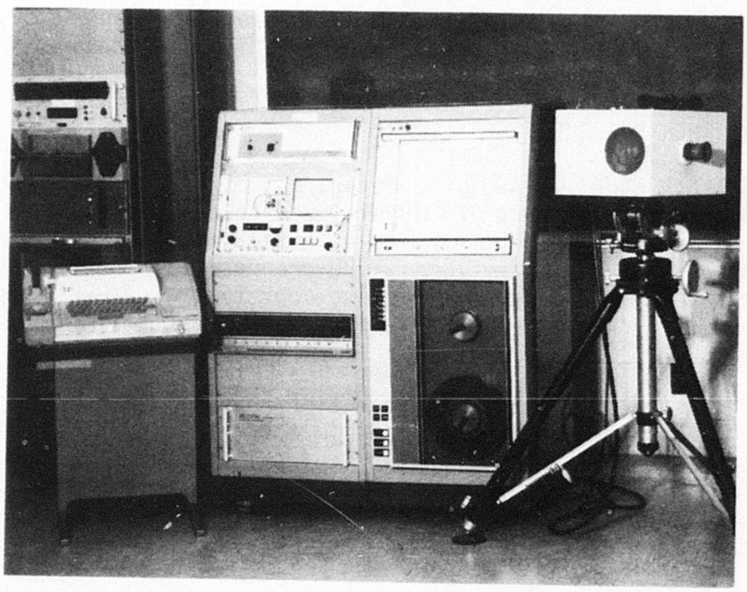


Figure 17. Block Fourier Transform Interferrometer Spectrometer

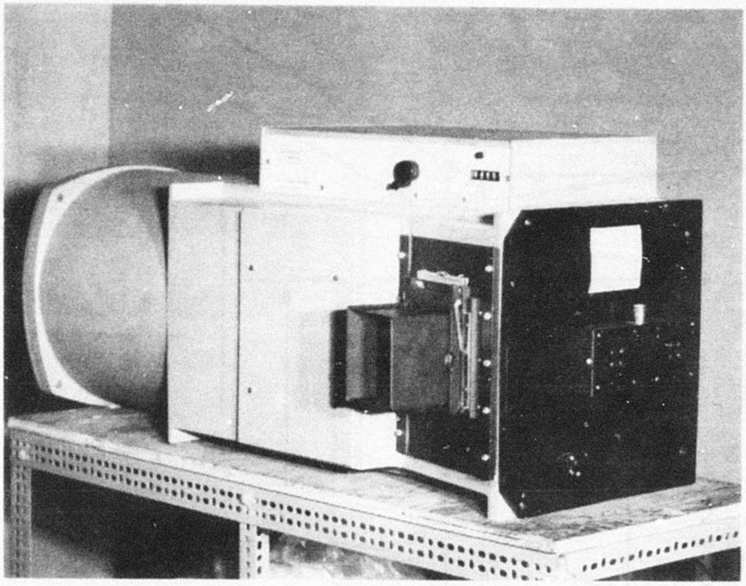


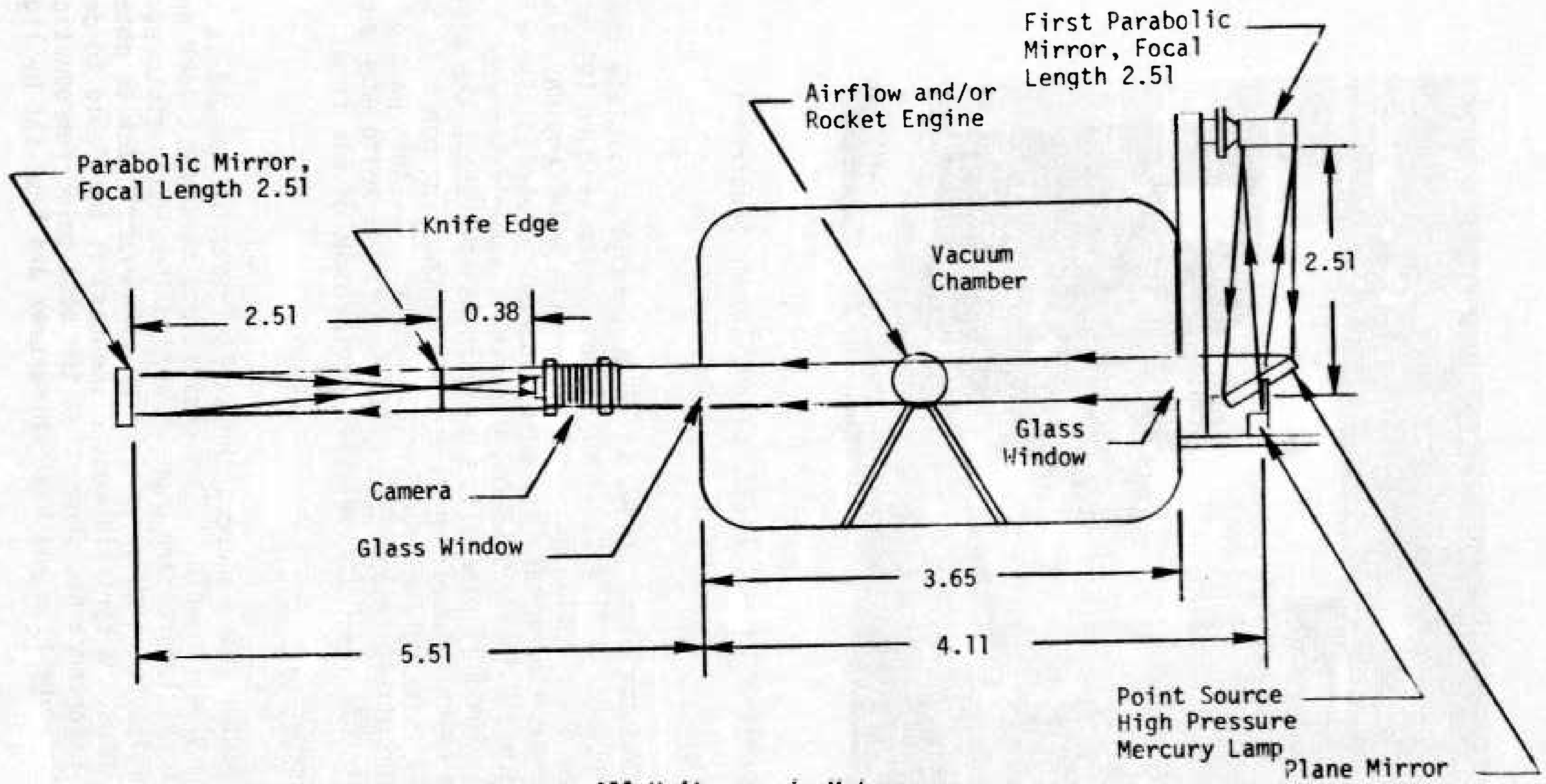
Figure 18. Jarrell-Ash Model 78-490 Czerny-Turner Spectrometer

5. SCHLIEREN SYSTEM

To produce a realistic plume study, it is necessary to simulate the air flow pattern which occurs in flight. A Schlieren system (Figure 19) provides a means of observing the air flow patterns around the model engine. The right side of Figure 19 shows the mercury arc point source, parabolic mirror [8-foot (2.44-m) focal length, 12-inch (30.48-cm) diameter], and plane mirror for folding the light path. The f/11 parabolic mirror is mounted above the plane mirror on a steel beam which is used for an optical bench. The bench is bolted to the chamber wall, assuring the necessary rigidity. The left part of Figure 19 shows the position of the second parabolic mirror, the knife edge and the Calumet camera. See Appendix C for selected photographs of air flow.

6. VISIBLE BAND PICTURE CAMERAS

A 16-mm motion-picture camera operating at 24 frames per second is used to record the visual plume in color. Two lenses, one having a 2-inch and the other a 1-inch focal length, are used to obtain the motion pictures. A 4x5 camera (Calumet) is used with a cut film or a Polaroid® back to obtain still pictures of plumes. A spot lightmeter (Pentax) is available to determine light levels. Experience has shown that the best color reproduction is obtained with tungsten type film and that aperatures are best set by light



All Units are in Meters

Figure 19. Schlieren System Diagram

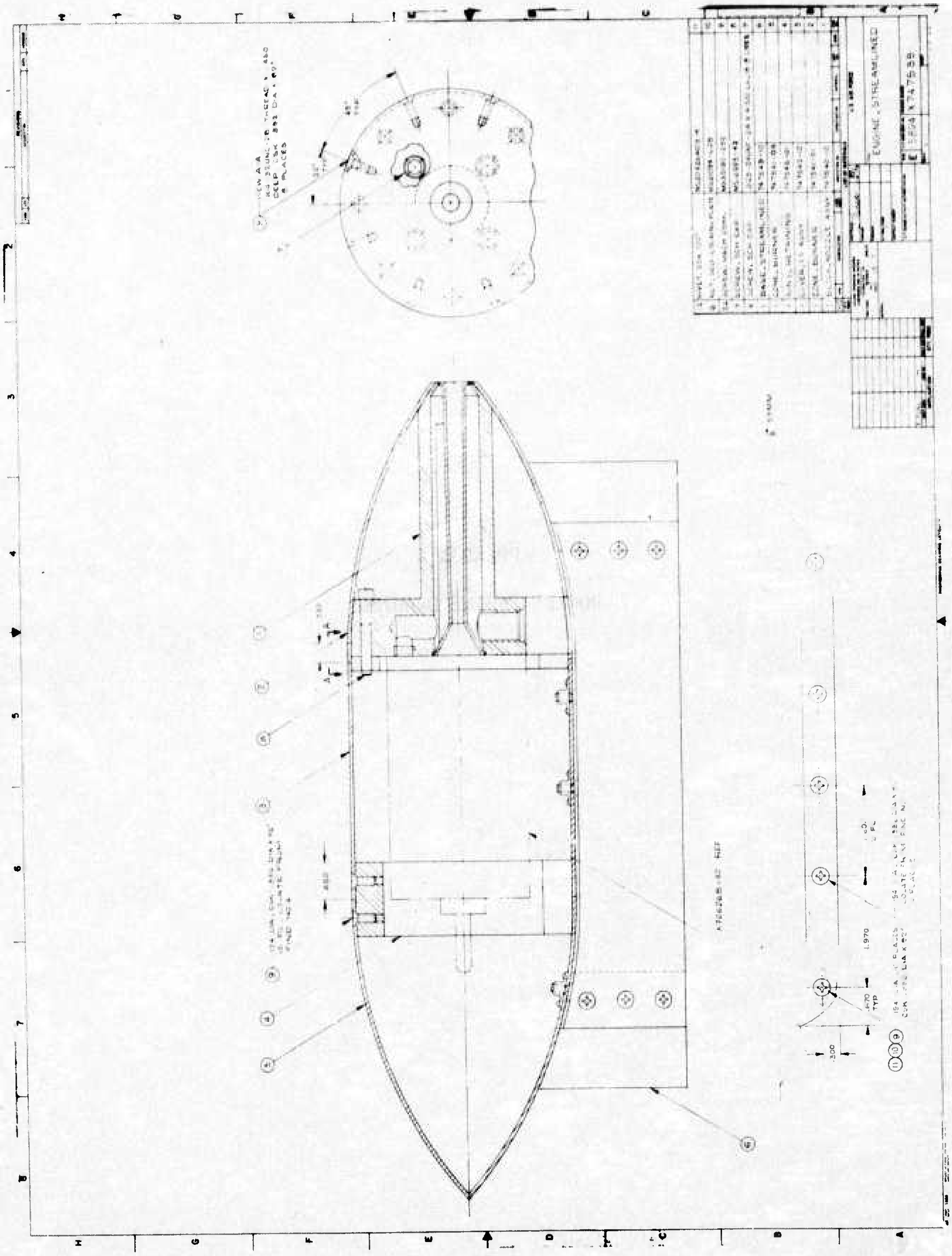
level readings from the first plume shock diamond. Color reproduction of plumes is very good with motion pictures; but is only fair for the stills, due to the many intermediate steps required to process, enlarge, and reproduce the final copy.

A closed circuit, black and white, television camera [Sony EV3400 System (Camera and 1/2-inch Recorder) G.E. Model 4TE20AIAT Camera and Sony EV200 1-inch Videocorder] is used to monitor exhaust plumes in real-time. A zoom lens with focal length between 15 and 150-mm permits close-up study of the visible spatial geometry. Data may be recorded on a 1-inch (Sony) video tape recorder. Generally, visible imaging is obtained from this one location, which affords a beam view of exhaust phenomena.

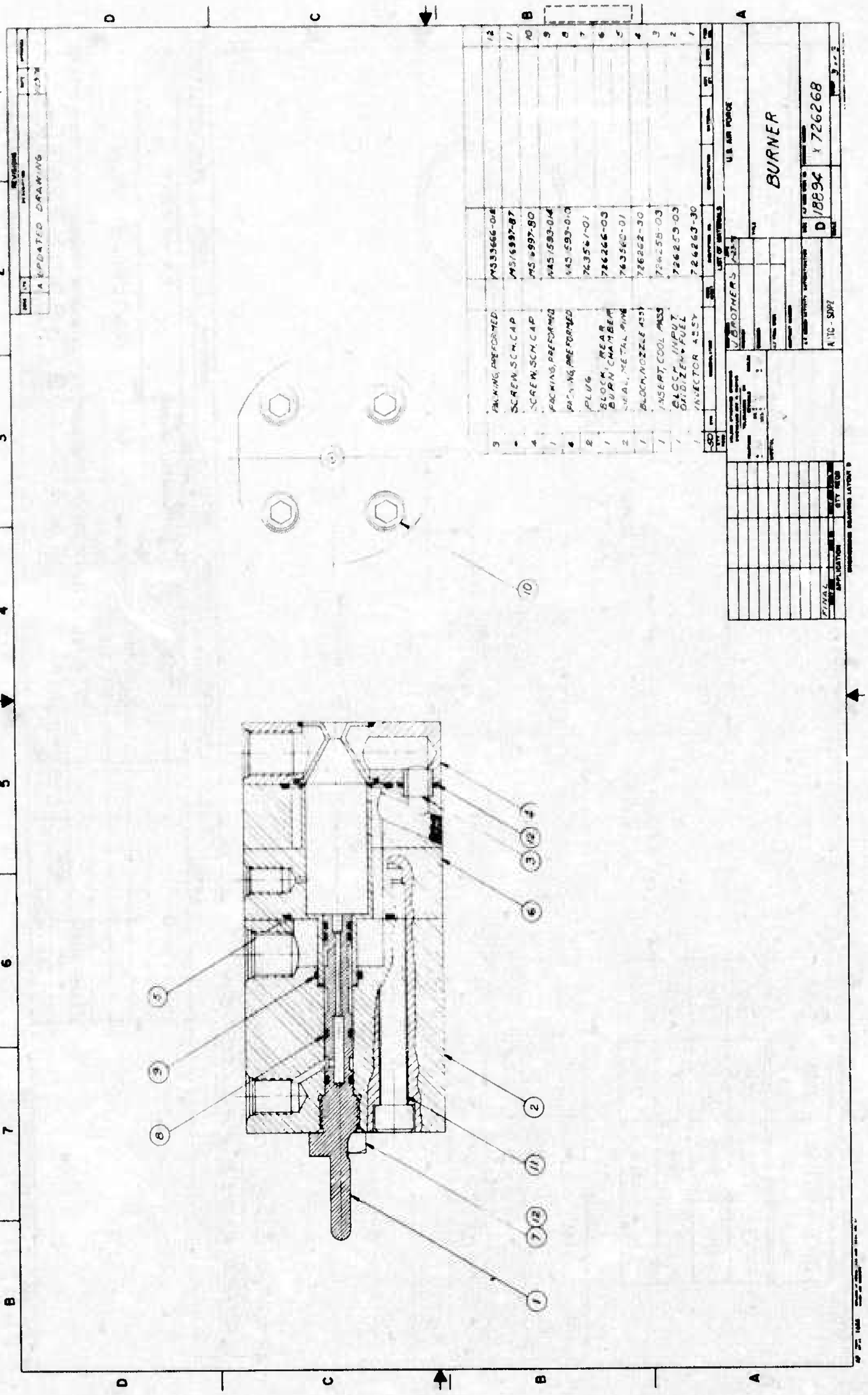
(The reverse of this page is blank)

APPENDIX A

ROCKET ENGINE DRAWINGS



Copy available to DDC does not permit fully legible reproduction



Copy available to DDC does not permit fully legible reproduction

DASH NO	DIM A	DIM B	DIM C
-03	.128	.195	.310
-05	.200	.195	.310
-07	NA	NA	.400
-11	NA	NA	.200

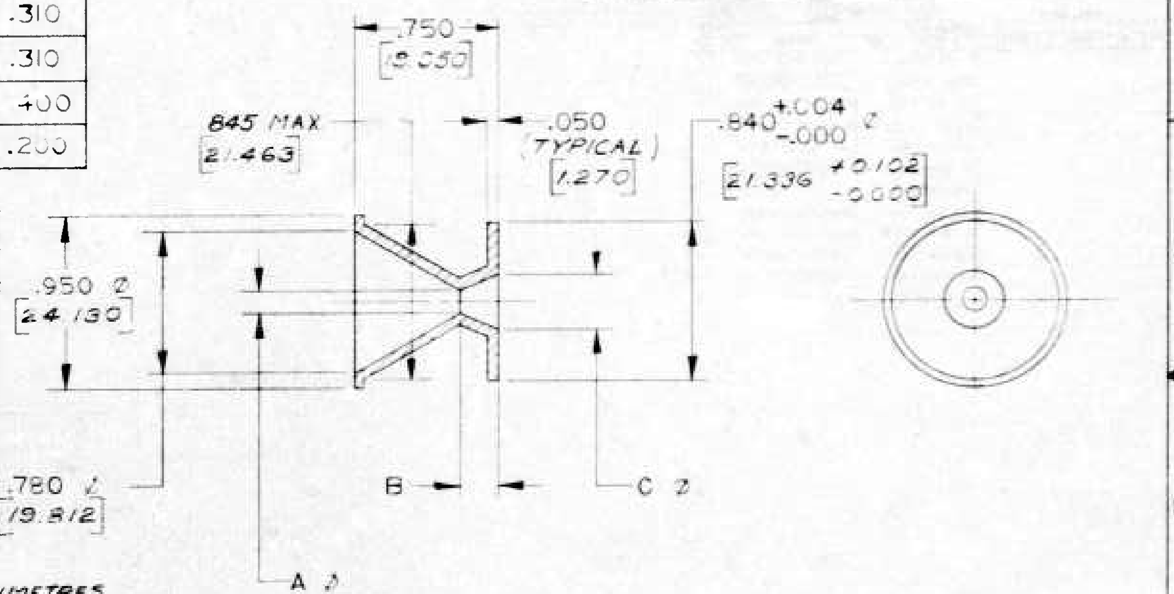
[METRIC]

DASH NO	DIM. A	DIM. B	DIM C
-03	[3.251]	[4.953]	[7.874]
-05	[5.080]	[4.953]	[7.874]
-07	—	—	[10160]
-11	—	—	[5.080]

DIMENSIONS IN [ ] ARE MILLIMETRES

THIRD ANGLE PROJECTION

REVISIONS				
ZONE	LTR	DESCRIPTION	DATE	APPROVED
	A	UPDATED DRAWING	1-23-76	



U.S. AIR FORCE

VENTURI, BURNER

MATERIAL: STEEL, STAINLESS AISI 302

ADTC-DLGZ

SIZE B 18894 X726256

SCALE 2:1 SHEET 2 OF 2

NEXT ASSY 7262630

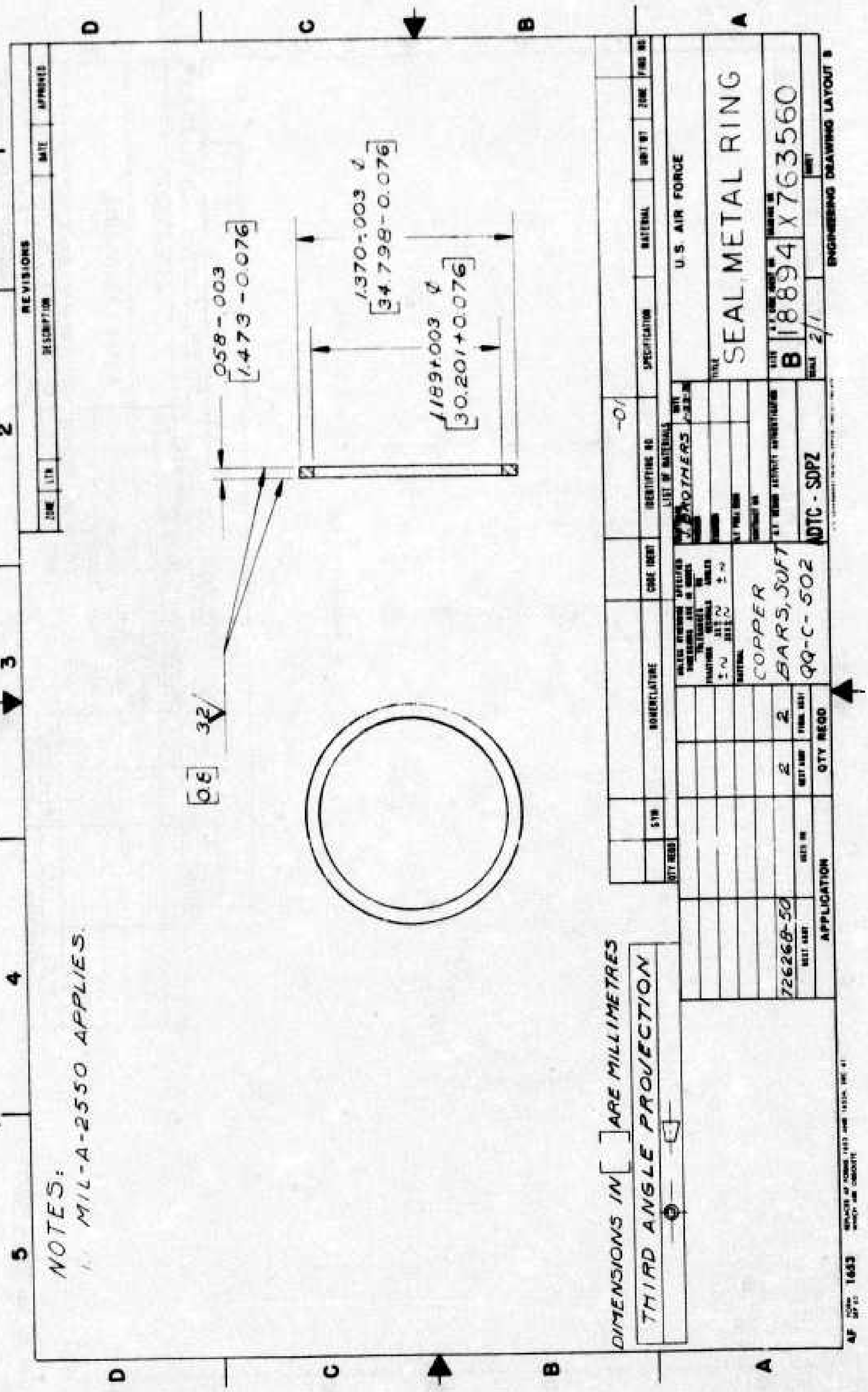
APPLICATION

QTY REQD

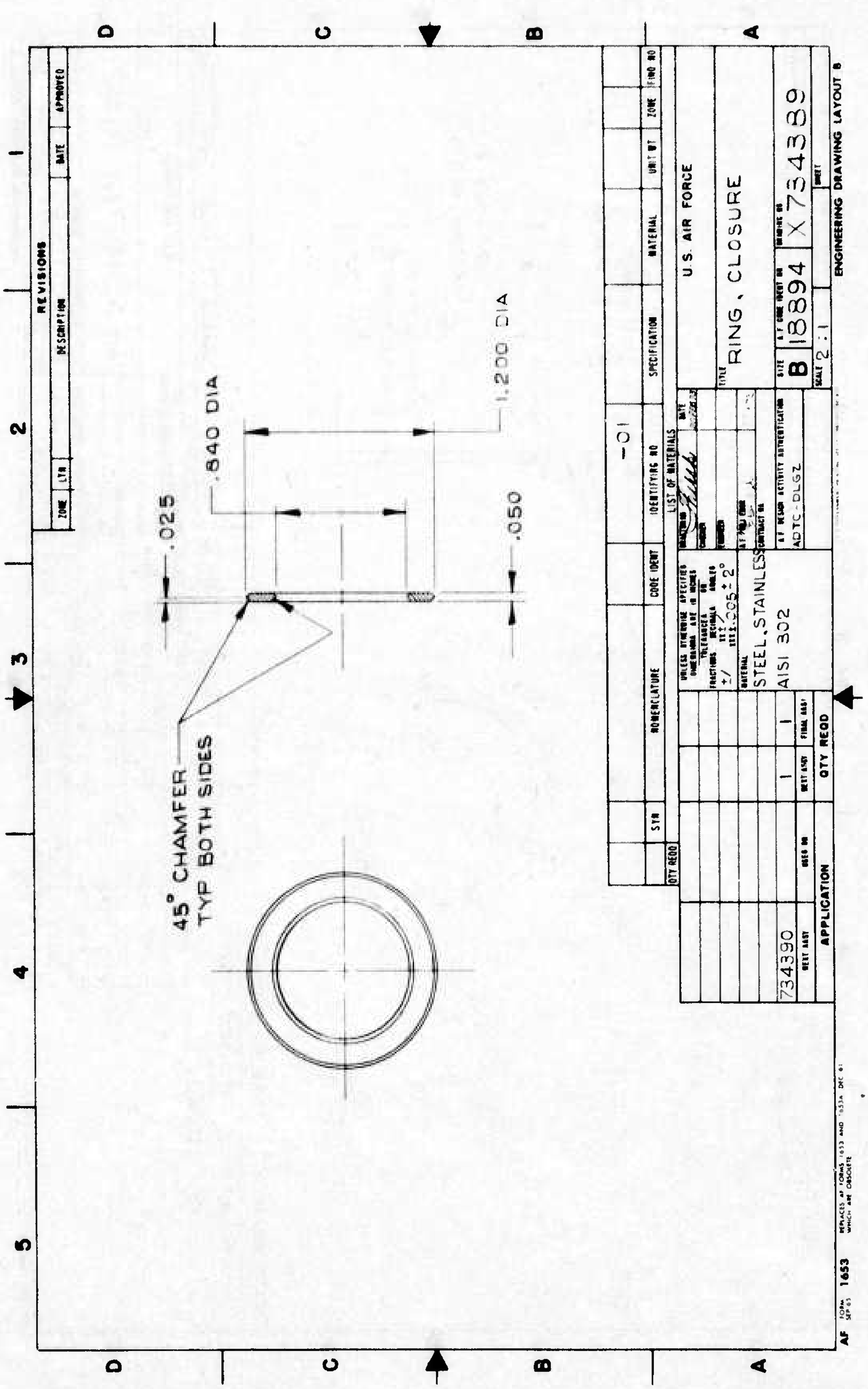
LIST OF MATERIALS

AF FORM 1653 SEP 65 REPLACES AF FORMS 1653 AND 1653A DEC 61 WHICH ARE OBSOLETE

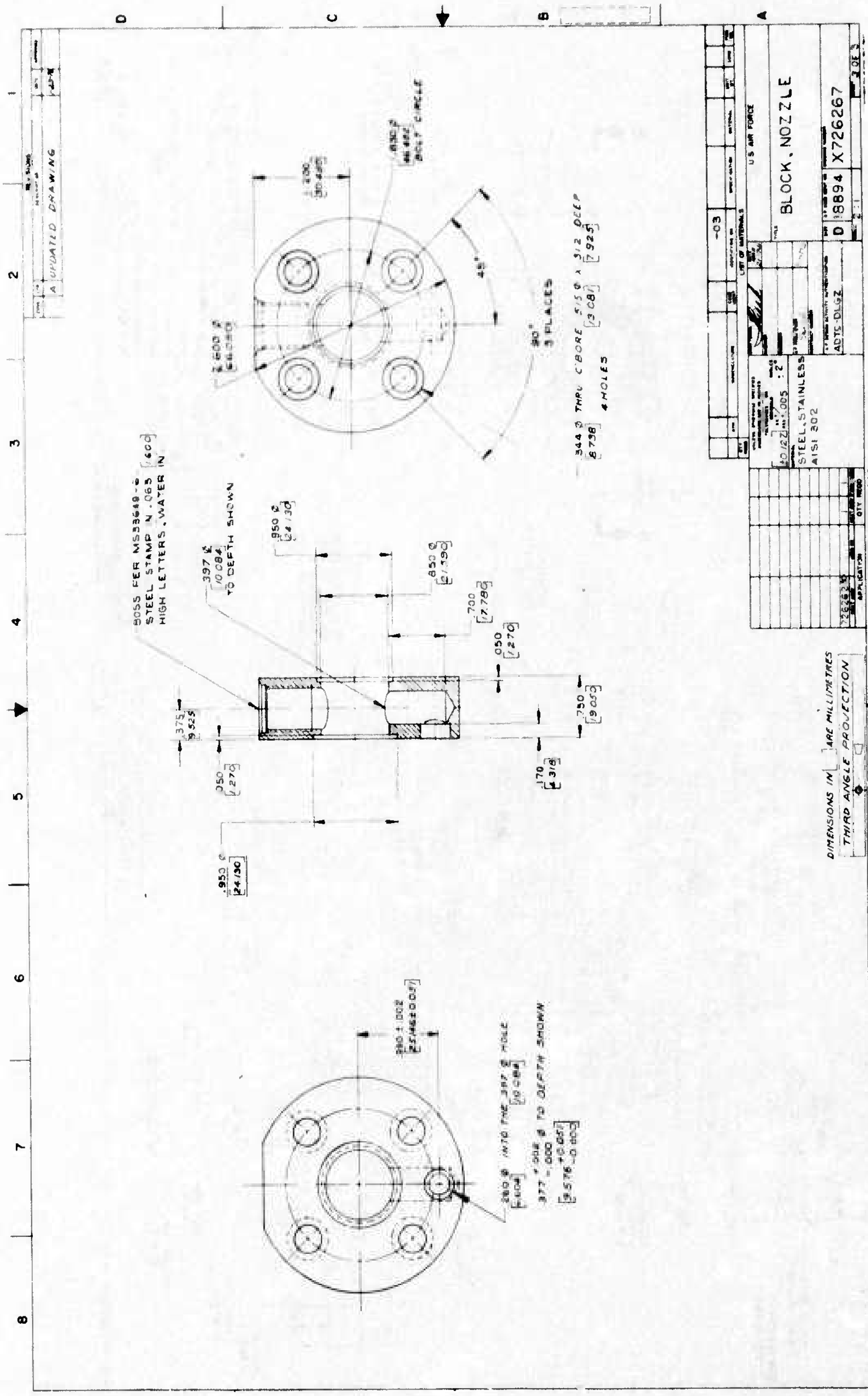
ENGINEERING DRAWING LAYOUT B



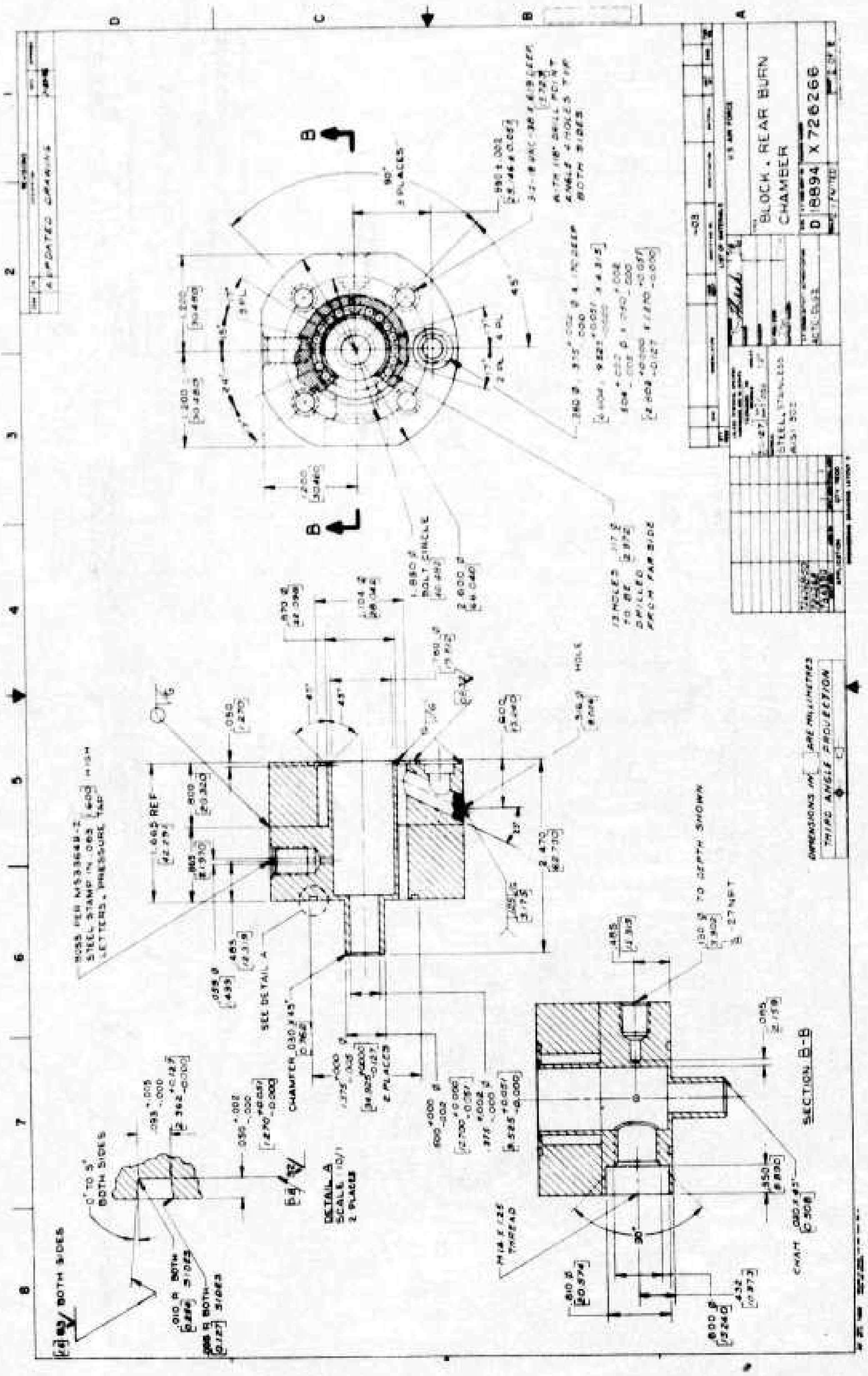
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
NOTES:
1. MIL-A-2550 APPLIES.
.058-.003
[1.473-0.076]
1.370-.003 ⌀
[34.798-0.076]
1.189+.003 ⌀
[30.201+0.076]
32
0.8
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
-01
IDENTIFYING NO
NOMENCLATURE
SPECIFICATION
MATERIAL
LIST OF MATERIAL
U.S. AIR FORCE
SEAL METAL RING
B 18894 X763560
SCALE 2/1
COPPER
BARS, SOFT
QQ-C-502
OTHERS
ADTC - SDPZ
72626B-50
2
2
NEXT ASSY
USED ON
APPLICATION
QTY REQD
ENGINEERING DRAWING LAYOUT B
AF FORM 1653

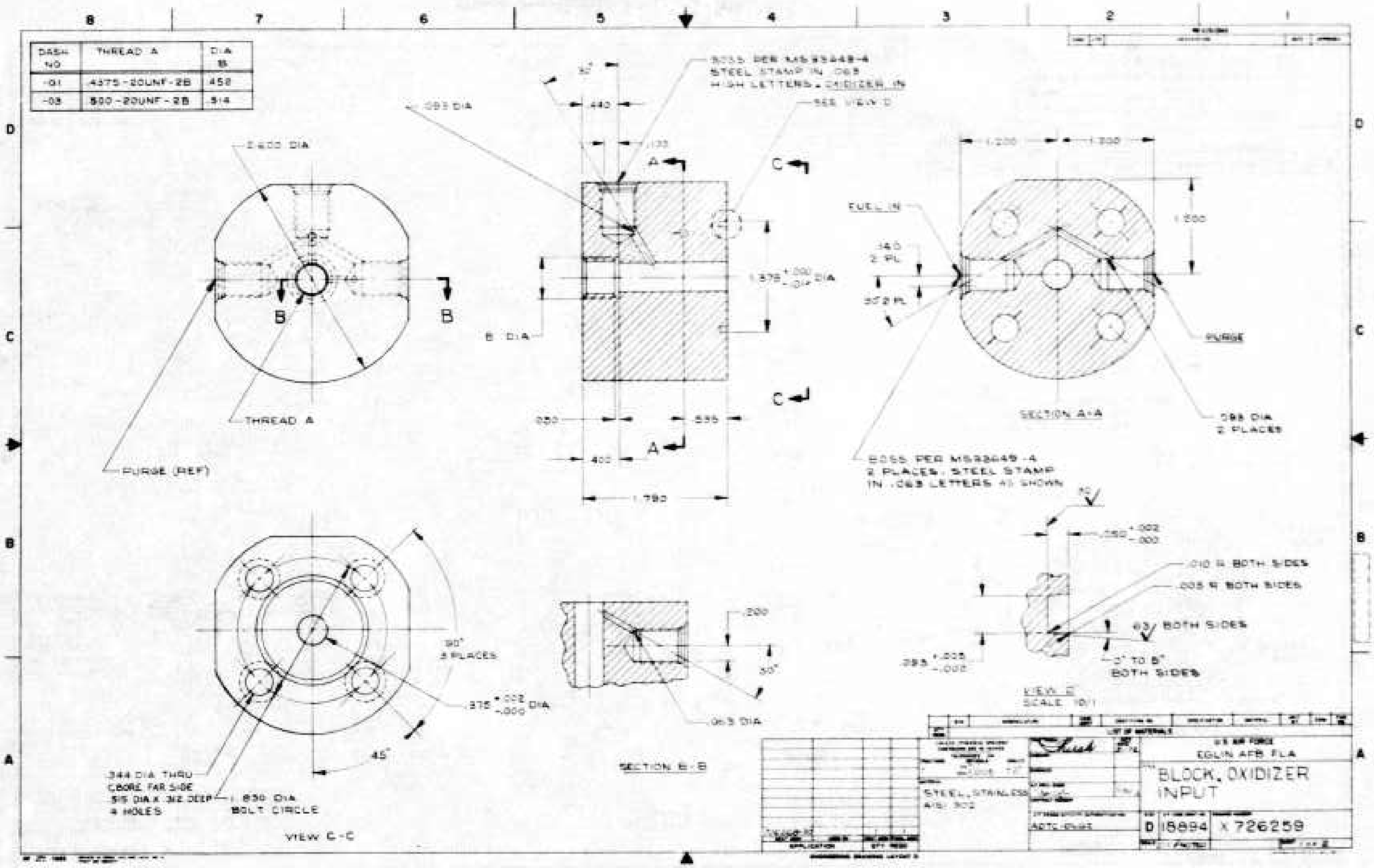


45° CHAMFER
TYP BOTH SIDES
.025
.840 DIA
1.200 DIA
.050
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
-01
IDENTIFYING NO
LIST OF MATERIALS
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES
FRACTIONS DECIMALS ANGLES
MATERIAL
STEEL, STAINLESS
AISI 302
734390
NEXT ASSY
USED ON
APPLICATION
QTY REQD
U.S. AIR FORCE
RING, CLOSURE
ADTC-DLGZ
B
18894
X734389
SCALE 2:1
ENGINEERING DRAWING LAYOUT B
AF FORM 1653

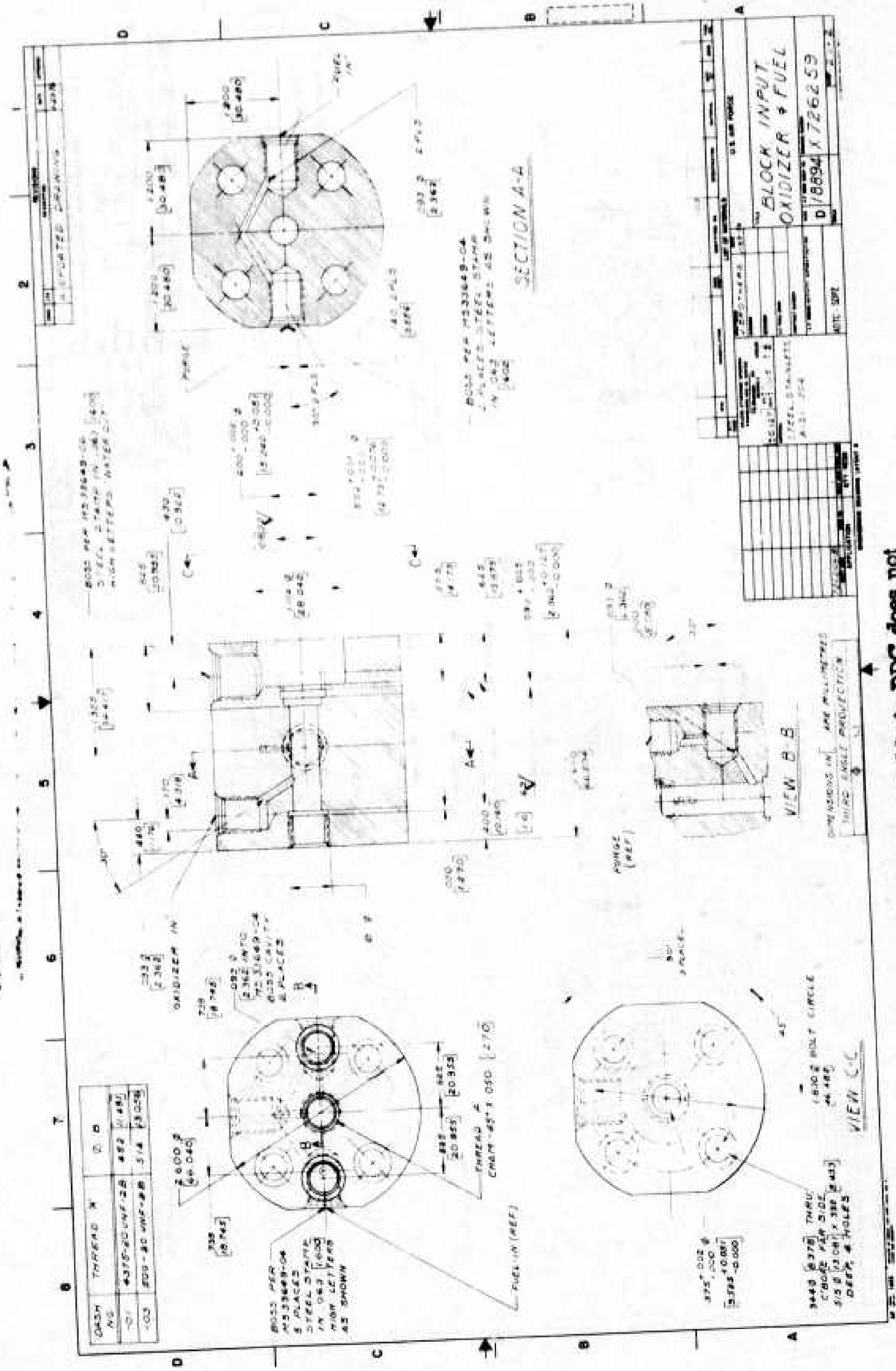


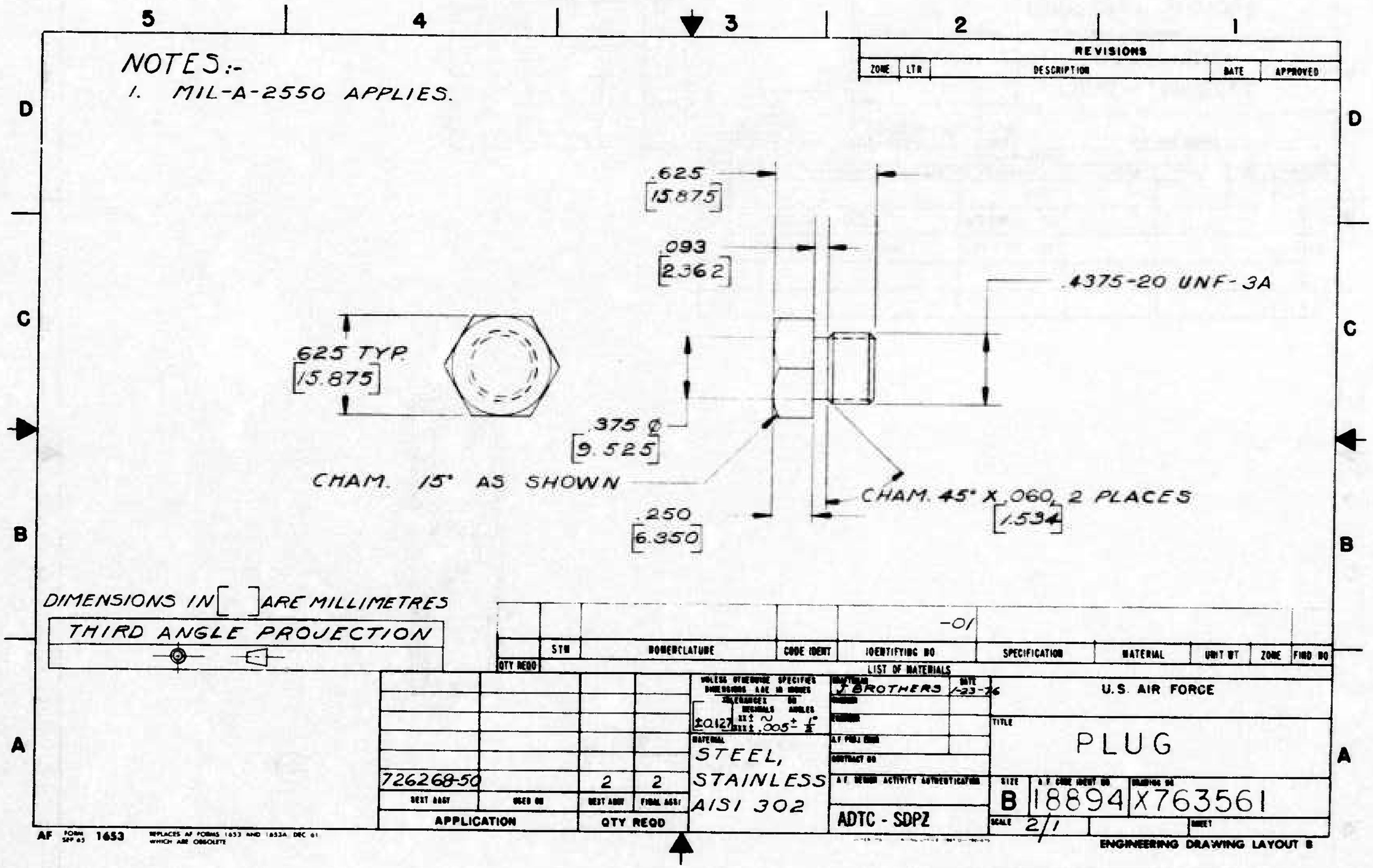
BLOCK, NOZZLE
D 18894 X726267
US AIR FORCE
STEEL, STAINLESS
AISI 302
ADTC-DLGZ
-03
A UPDATED DRAWING
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
BOLT CIRCLE
90° 3 PLACES
4 HOLES
TO DEPTH SHOWN

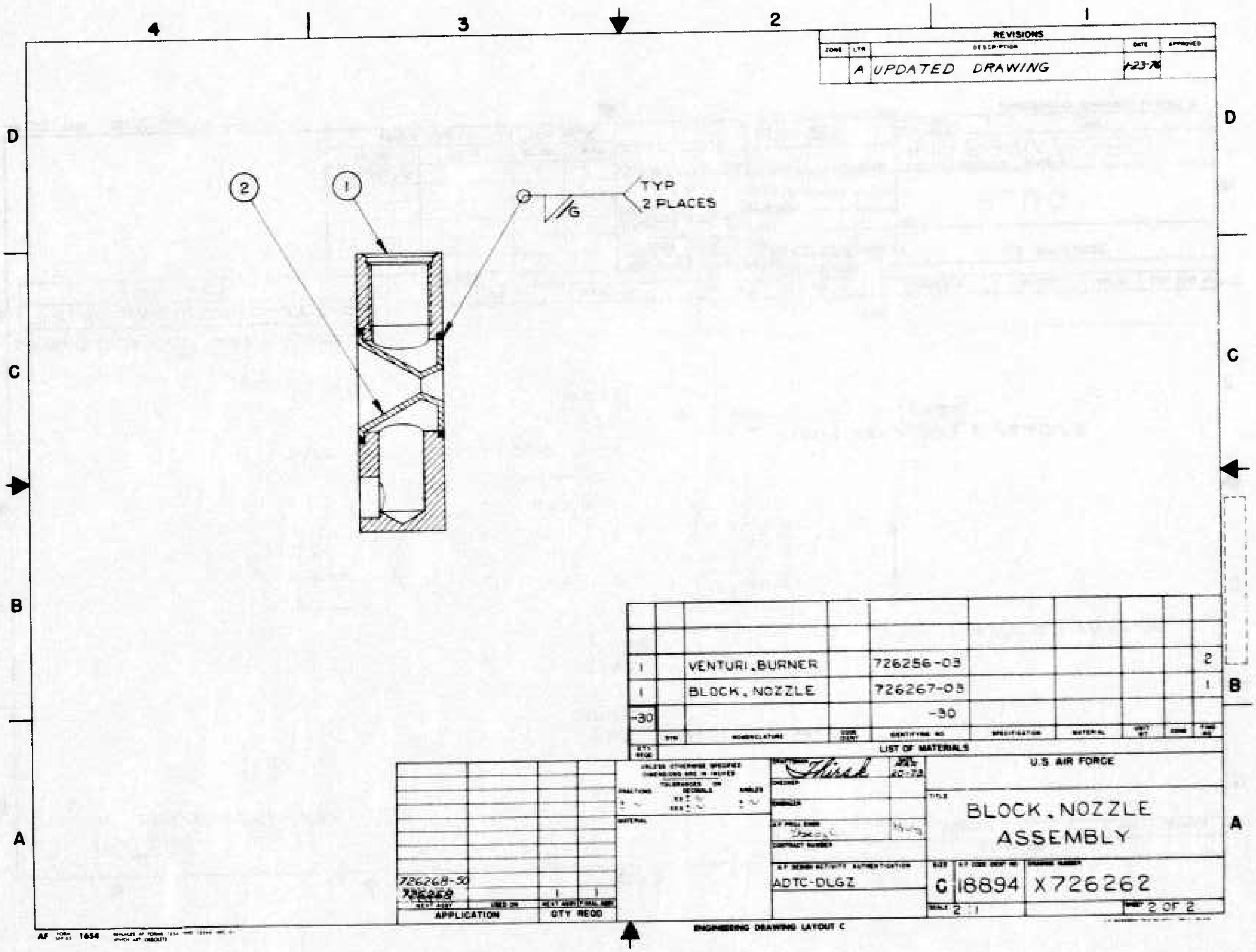

BLOCK, REAR BURN CHAMBER
D 18894 X726266
SECTION B-B
DETAIL A
THIRD ANGLE PROJECTION

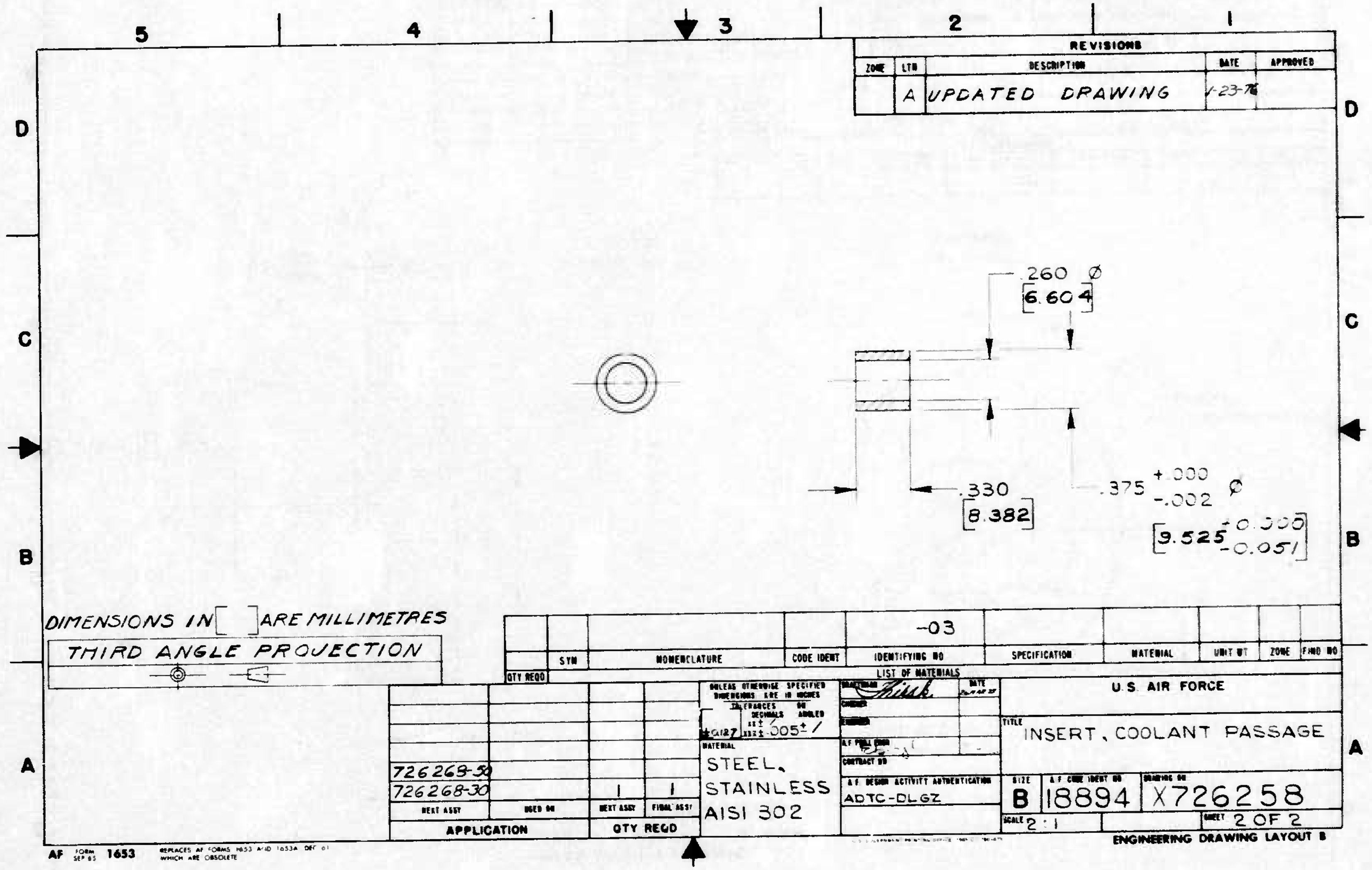


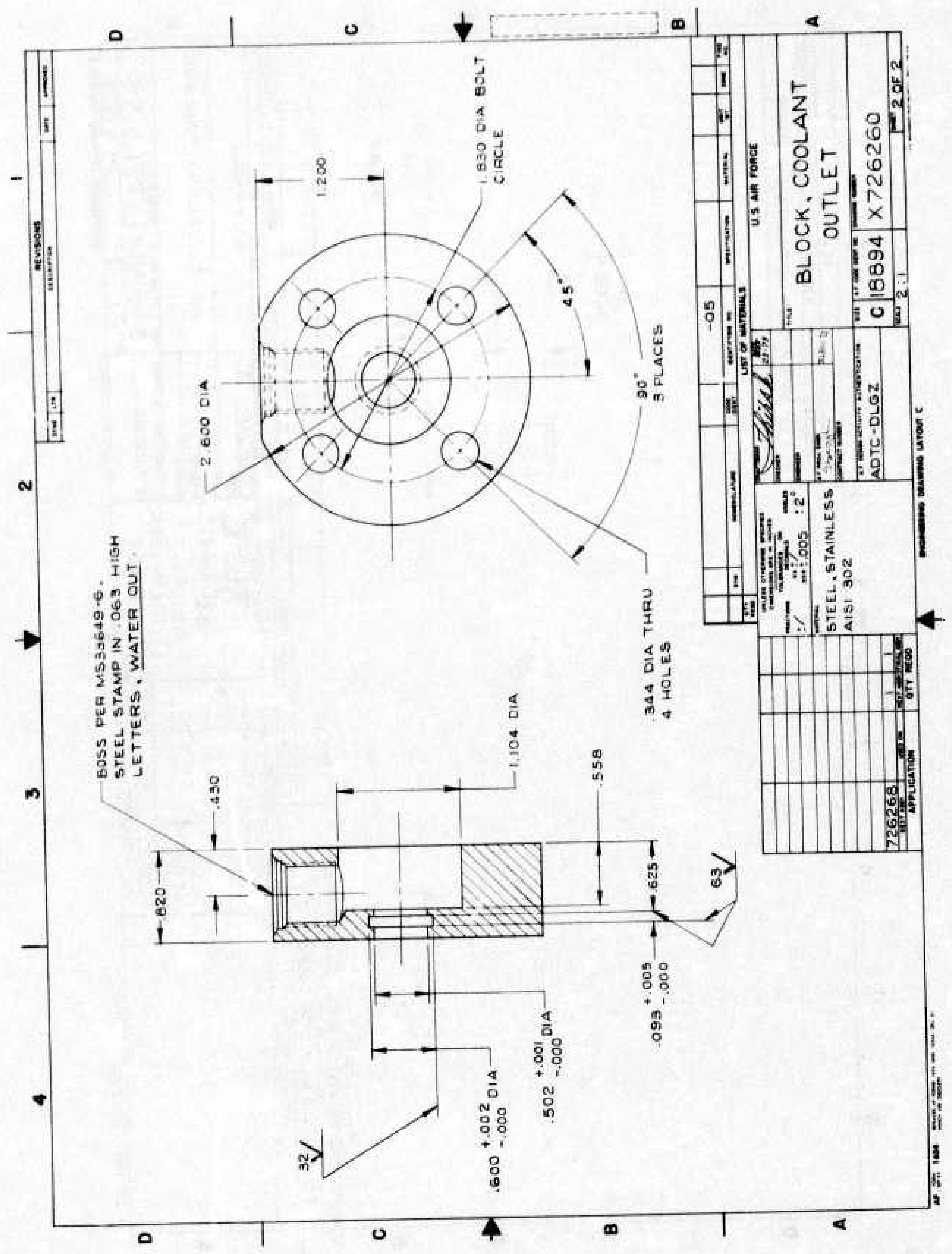
DASH NO
THREAD A
DIA B
-01
.4375-20UNF-2B
.452
-03
.500-20UNF-2B
.514
2.600 DIA
THREAD A
PURGE (REF)
.093 DIA
BOSS PER MS33649-4
STEEL STAMP IN .063
HIGH LETTERS - OXIDIZER IN
SEE VIEW D
B DIA
1.780
FUEL IN
PURGE
SECTION A-A
.098 DIA
2 PLACES
BOSS PER MS33649-4
2 PLACES. STEEL STAMP
IN .063 LETTERS AS SHOWN
.010 R BOTH SIDES
.005 R BOTH SIDES
BOTH SIDES
BOTH SIDES
VIEW D
SCALE 10/1
90°
3 PLACES
45°
.063 DIA
SECTION B-B
.344 DIA THRU
CBORE FAR SIDE
.515 DIA X .312 DEEP
4 HOLES
1.830 DIA
BOLT CIRCLE
VIEW C-C
STEEL, STAINLESS
AISI 302
U.S. AIR FORCE
EGLIN AFB FLA
BLOCK, OXIDIZER
INPUT
D 18894 X 726259

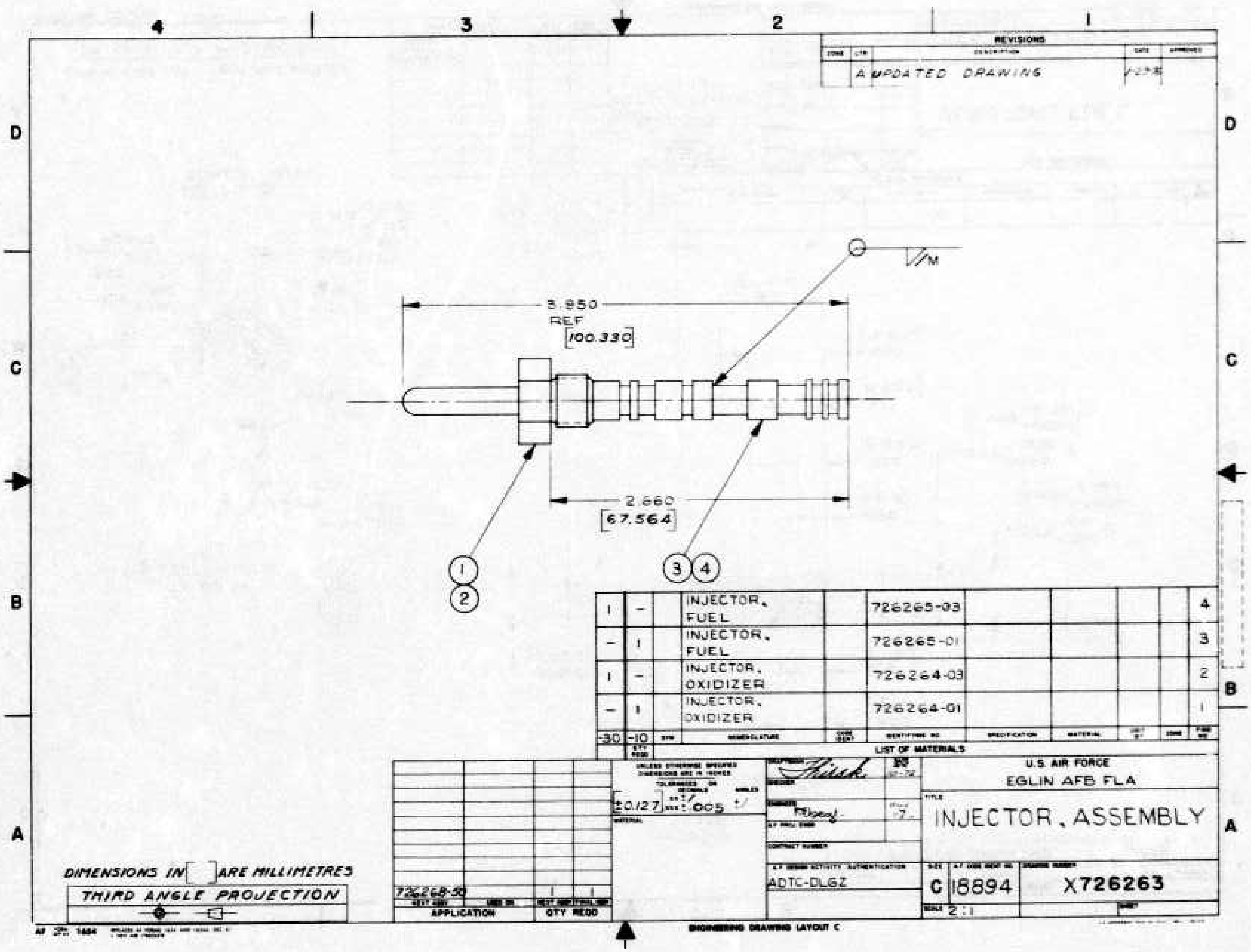

BLOCK INPUT OXIDIZER & FUEL
SECTION A-A
VIEW B-B
VIEW C-C
OXIDIZER IN
FUEL IN (REF)

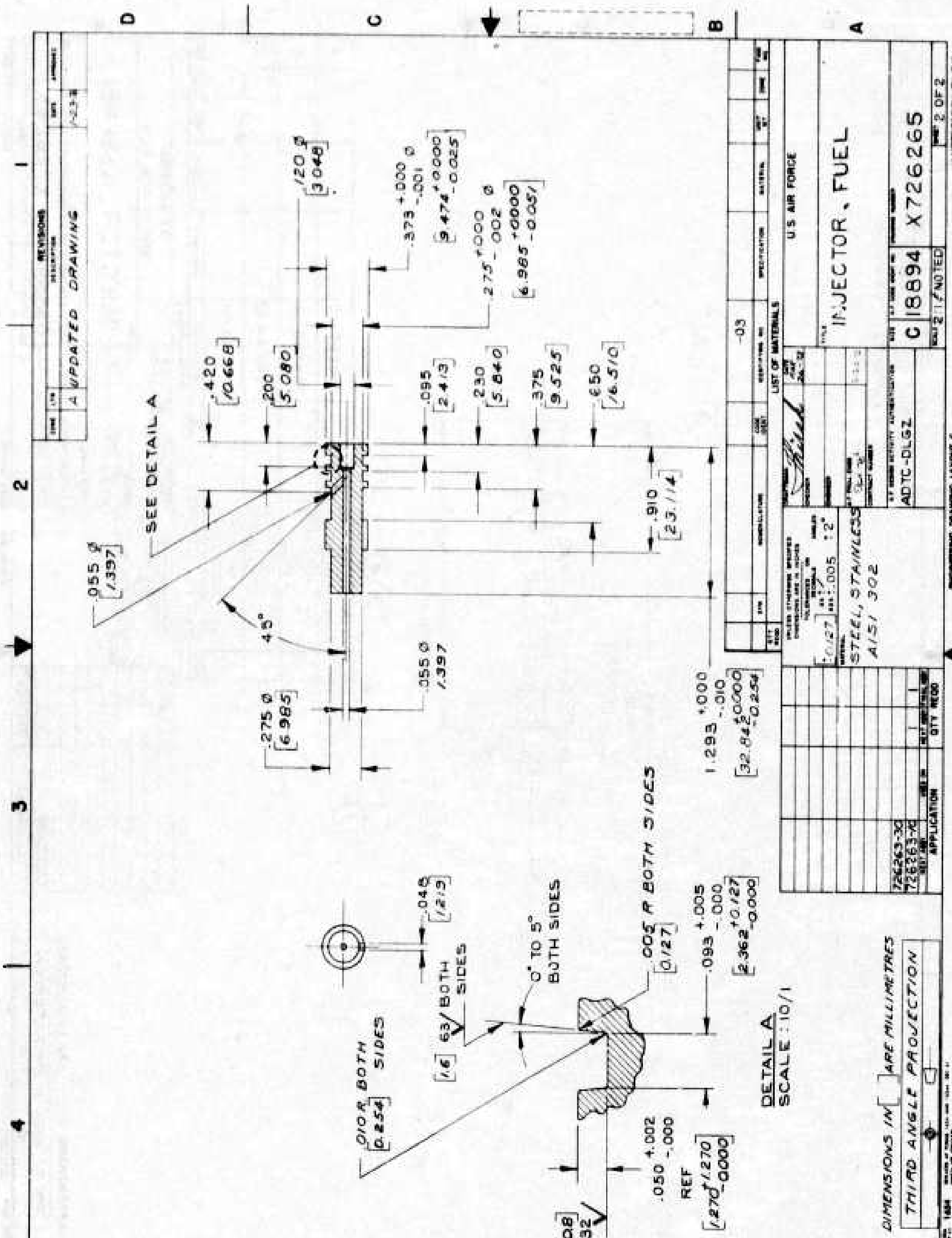

NOTES:-
1. MIL-A-2550 APPLIES.
.625
[15.875]
.093
[2.362]
.4375-20 UNF-3A
625 TYP.
[15.875]
.375 ⌀
[9.525]
CHAM. 15° AS SHOWN
CHAM. 45° X .060, 2 PLACES
[1.534]
.250
[6.350]
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
-01
QTY REQD
STK
NOMENCLATURE
CODE IDENT
IDENTIFYING NO
SPECIFICATION
MATERIAL
UNIT WT
ZONE
FIND NO
LIST OF MATERIALS
J. BROTHERS
1-23-76
±0.127
.005
STEEL,
STAINLESS
AISI 302
U.S. AIR FORCE
TITLE
PLUG
726268-50
NEXT ASSY
USED ON
2
2
NEXT ASSY
FINAL ASSY
APPLICATION
QTY REQD
ADTC - SDPZ
SIZE
B
18894
X763561
SCALE
2/1
SHEET
ENGINEERING DRAWING LAYOUT B
AF FORM SEP 65 1653
REPLACES AF FORMS 1653 AND 1653A, DEC 61, WHICH ARE OBSOLETE

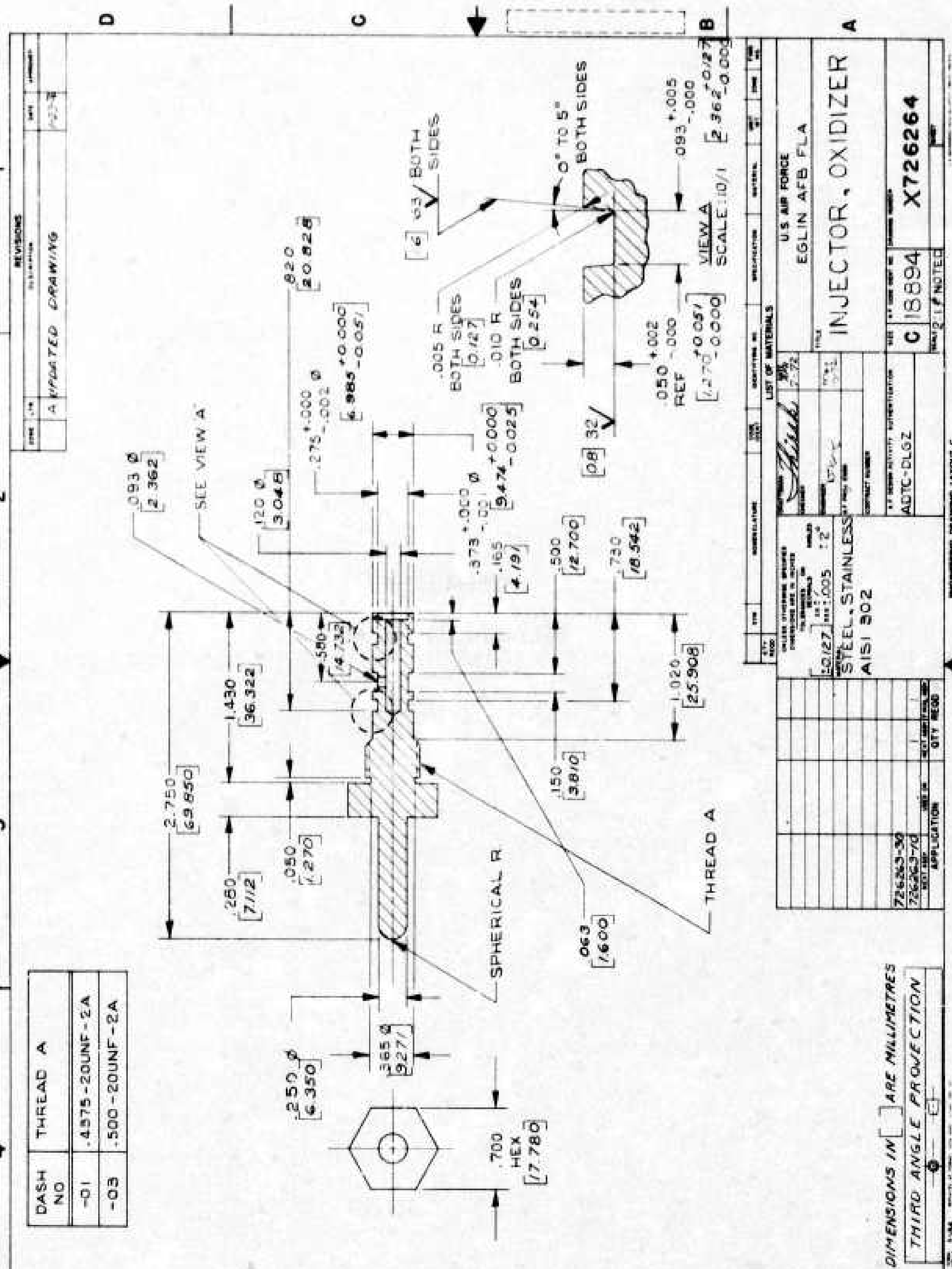

REVISIONS
ZONE
LTR
DESCRIPTION
DATE
APPROVED
A UPDATED DRAWING
TYP
2 PLACES
G
1
2
VENTURI, BURNER
726256-03
BLOCK, NOZZLE
726267-03
-30
QTY REQD
NOMENCLATURE
IDENTIFYING NO.
SPECIFICATION
MATERIAL
LIST OF MATERIALS
U.S. AIR FORCE
TITLE
BLOCK, NOZZLE
ASSEMBLY
ADTC-DLGZ
C
18894
X726262
2 OF 2
726268-30
NEXT ASSY
USED ON
APPLICATION
QTY REQD
ENGINEERING DRAWING LAYOUT C
AF FORM 1654


REVISIONS
ZONE LTR DESCRIPTION DATE APPROVED
A UPDATED DRAWING 1-23-76
.260 Ø
[6.604]
.330
[8.382]
.375 +.000 -.002 Ø
[9.525 +0.000 -0.051]
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
-03
QTY REQD SYM NOMENCLATURE CODE IDENT IDENTIFYING NO SPECIFICATION MATERIAL UNIT WT ZONE FIND NO
LIST OF MATERIALS
726268-50
726268-30
NEXT ASSY USED ON
APPLICATION
NEXT ASSY FINAL ASSY
QTY REQD
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS ANGLES
MATERIAL
STEEL, STAINLESS AISI 302
CONTRACT NO
A.F. DESIGN ACTIVITY AUTHENTICATION
ADTC-DLGZ
U.S. AIR FORCE
TITLE
INSERT, COOLANT PASSAGE
SIZE B
A.F. CODE IDENT NO 18894
DRAWING NO X726258
SCALE 2:1
SHEET 2 OF 2
ENGINEERING DRAWING LAYOUT B
AF FORM 1653
REPLACES AF FORMS 1653 AND 1653A DEC 61 WHICH ARE OBSOLETE


REVISIONS
DESCRIPTION
DATE
APPROVED
BOSS PER MS33649-6, STEEL STAMP IN .063 HIGH LETTERS, WATER OUT.
.430
.820
1.104 DIA
.558
.625
63
.093 +.005 -.000
.502 +.001 -.000 DIA
.600 +.002 -.000 DIA
32
2.600 DIA
1.200
1.830 DIA BOLT CIRCLE
45°
90° 3 PLACES
.344 DIA THRU 4 HOLES
-05
LIST OF MATERIALS
U.S. AIR FORCE
BLOCK, COOLANT OUTLET
STEEL, STAINLESS AISI 302
ADTC-DLGZ
±2°
±.005
C 18894 X726260
SCALE 2:1
2 OF 2
726268
APPLICATION
QTY REQD
ENGINEERING DRAWING LAYOUT C


REVISIONS
A UPDATED DRAWING
3.950 REF [100.330]
2.660 [67.564]
1 2
3 4
INJECTOR, FUEL 726265-03 4
INJECTOR, FUEL 726265-01 3
INJECTOR, OXIDIZER 726264-03 2
INJECTOR, OXIDIZER 726264-01 1
LIST OF MATERIALS
±0.127 .005
U.S AIR FORCE
EGLIN AFB FLA
INJECTOR, ASSEMBLY
ADTC-DLGZ
C 18894 X726263
SCALE 2:1
726268-50
APPLICATION
QTY REQD
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
ENGINEERING DRAWING LAYOUT C

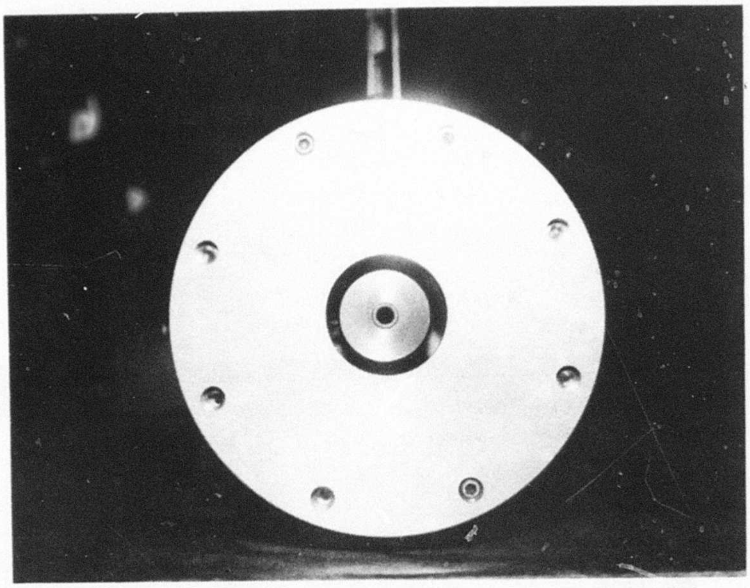

REVISIONS
UPDATED DRAWING
SEE DETAIL A
DETAIL A
SCALE: 10/1
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION
STEEL, STAINLESS
AISI 302
ADTC-DLGZ
U.S AIR FORCE
INJECTOR, FUEL
C 18894
X726265
2 OF 2



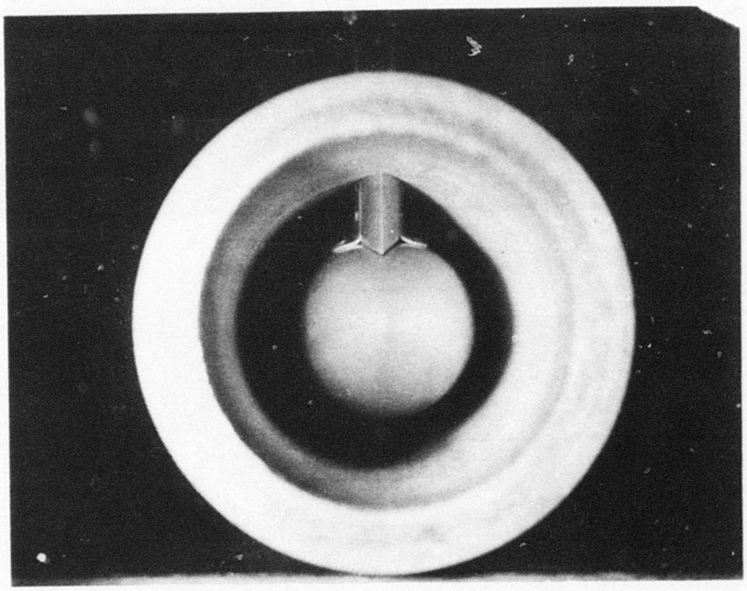
REVISIONS
A UPDATED DRAWING
DASH NO | THREAD A
-01 | .4375-20UNF-2A
-03 | .500-20UNF-2A
.700 HEX [17.780]
.250 Ø [6.350]
.365 Ø [9.271]
.280 [7.112]
.050 [1.270]
2.750 [69.850]
1.430 [36.322]
.580 [14.732]
.093 Ø [2.362]
SEE VIEW A
.120 Ø [3.048]
.820 [20.828]
.275 +.000 -.002 Ø [6.985 +0.000 -0.051]
.373 +.000 -.001 Ø [9.474 +0.000 -0.025]
.165 [4.191]
.500 [12.700]
.730 [18.542]
1.020 [25.908]
.150 [3.810]
.063 [1.600]
SPHERICAL R
THREAD A
.005 R BOTH SIDES [0.127]
.010 R BOTH SIDES [0.254]
63 BOTH SIDES
0° TO 5° BOTH SIDES
.093 +.005 -.000 [2.362 +0.127 -0.000]
.050 +.002 -.000 REF [1.270 +0.051 -0.000]
VIEW A SCALE 10/1
STEEL, STAINLESS AISI 302
U.S. AIR FORCE
EGLIN AFB FLA
INJECTOR, OXIDIZER
C 18894 X726264
ADTC-DLGZ
LIST OF MATERIALS
APPLICATION
DIMENSIONS IN [ ] ARE MILLIMETRES
THIRD ANGLE PROJECTION

APPENDIX B

STREAMLINED ENGINE

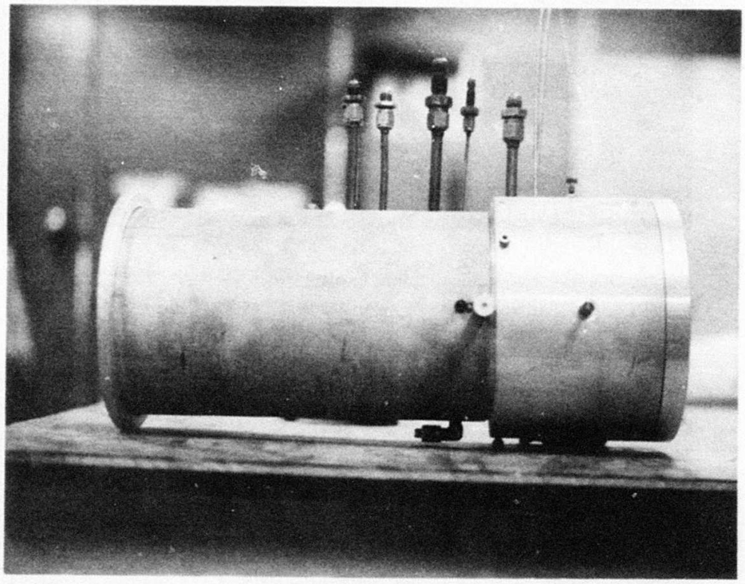


(a) Rear Aspect



(b) Front Aspect

Figure B-1. Streamlined Engine



(c) Side Aspect

Figure B-1. Streamlined Engine (Concluded)

APPENDIX C

TYPICAL AIRFLOW SCHLIEREN PHOTOGRAPHS AND FLOW MAPPING

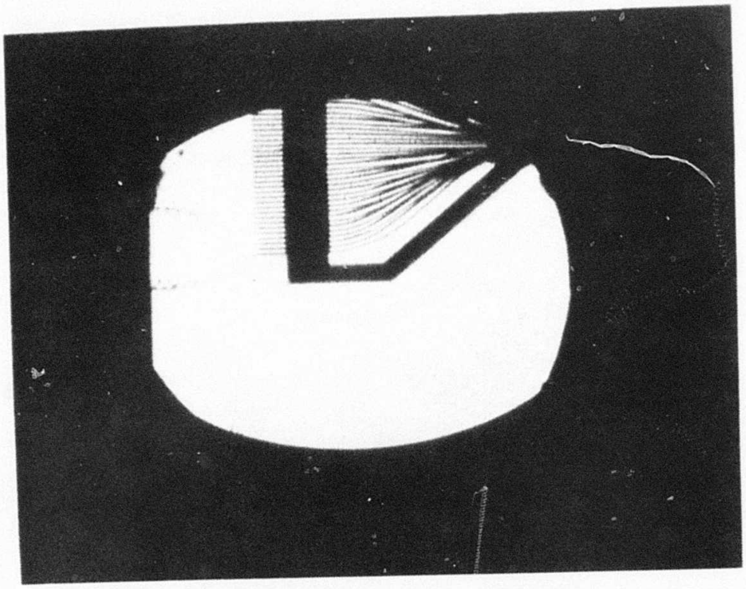


Figure C-1. Schlieren Photo of Subscale HAST at 19.6 km with Pressure Probe

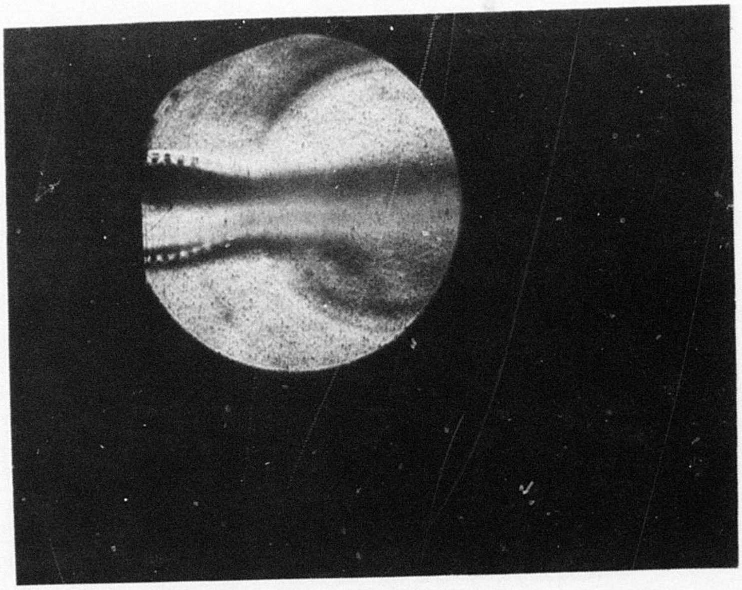


Figure C-2. Schlieren of Air Jet

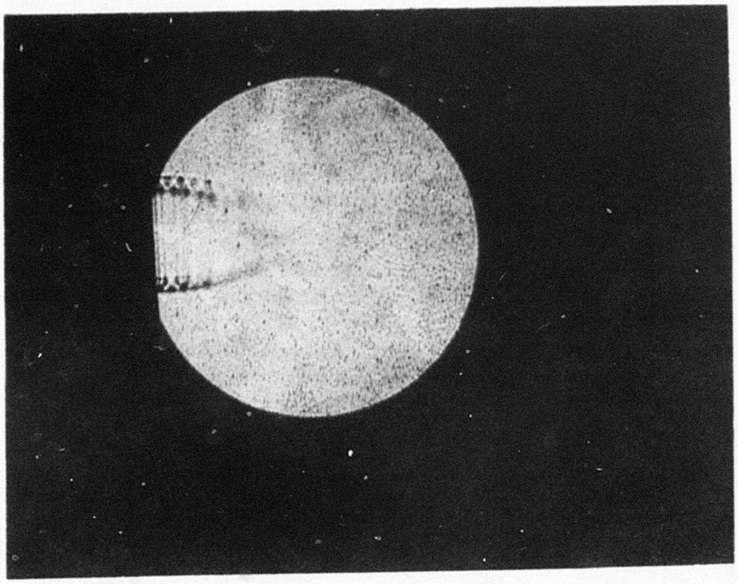


Figure C-3. Airflow Schlieren without Engine Operating

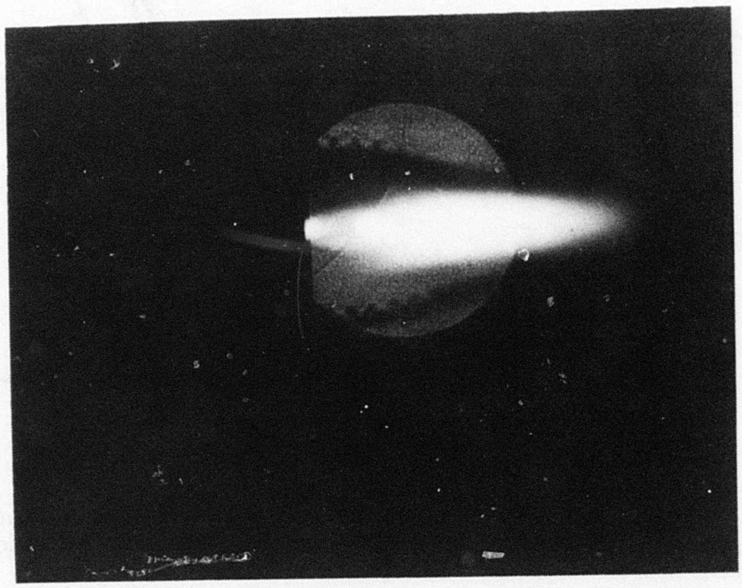


Figure C-4. Airflow Schlieren with Engine Operating

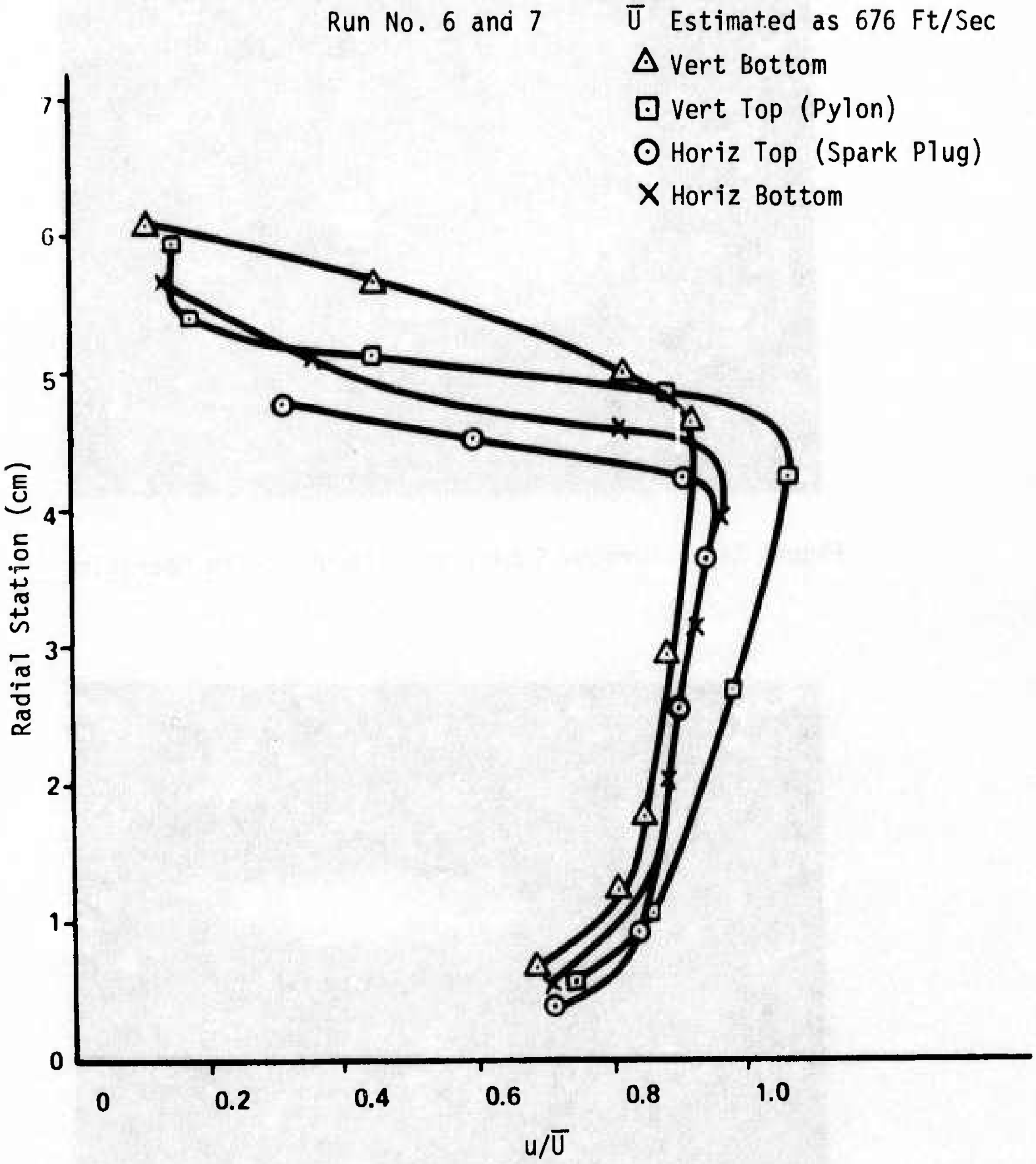
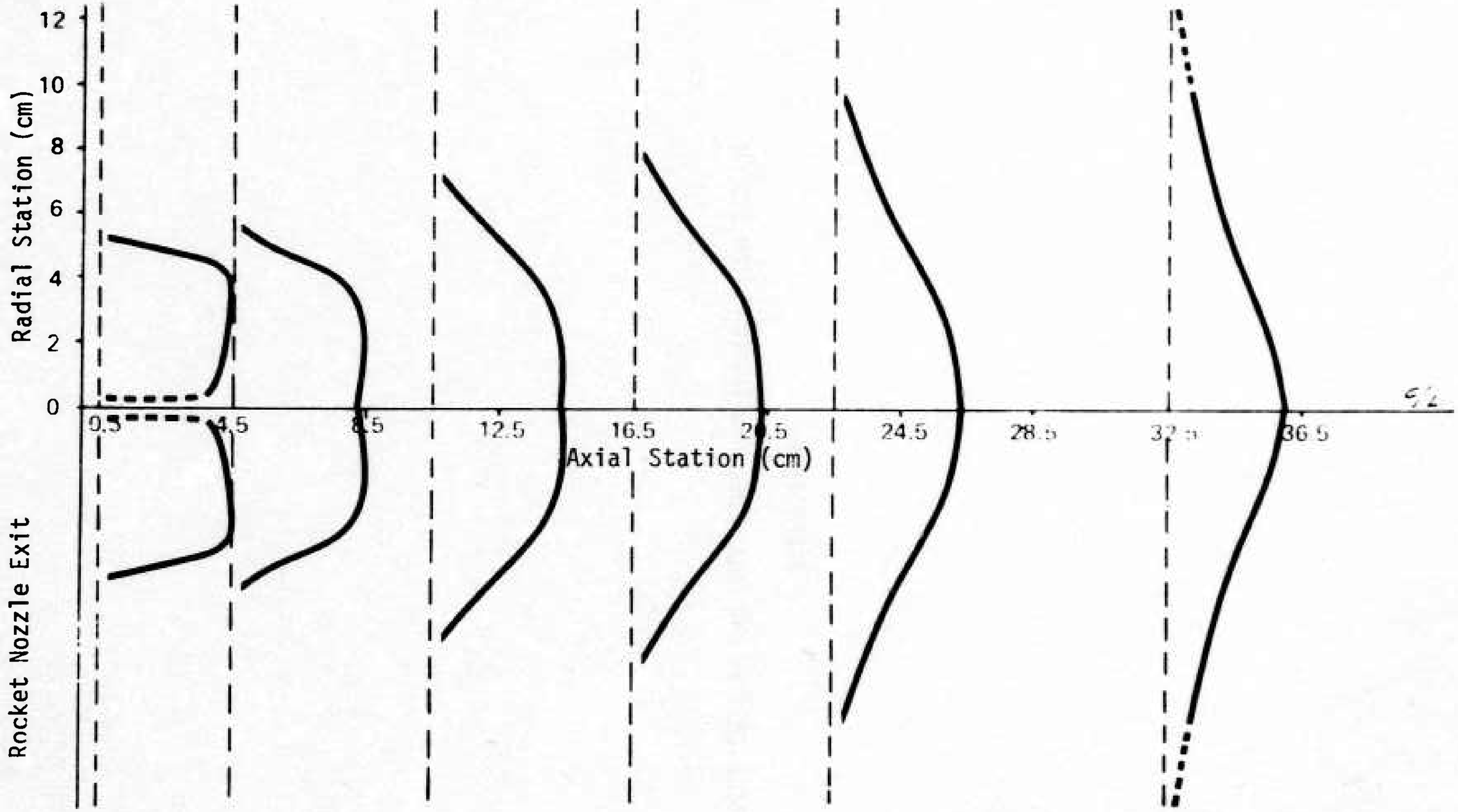


Figure C-5. Velocity Distribution 0.5-cm Aft of Rocket Nozzle
2.5-Inch Diameter Choke, 20,000-Foot Altitude



Run No. 6 Top
U = 676 Ft/Sec

Figure C-6. Velocity Distribution in Annular Jet, 2.5-Inch Diameter Choke, 20,000 Feet

APPENDIX D

SPECIFICATIONS FOR AGA MODEL 680 THERMOVISION SYSTEM

CAMERA UNIT 680

TYPE

Real-time optical/mechanical scanning, with straight-through optics and built-in aperture and filter selection.

OPTICS

Two different field of view infrared lenses available:

Field of View:

10x10 degrees (174x174 mrad)	25x25 degrees (436x436 mrad)

Range of Focus[a]:

0.95-m to ∞	0.6-m to ∞

Scanned Area:

11.5x11.5-cm at 0.95-m	23x23-cm at 0.6-m

4.2x4.2-cm (at 0.58-m with 45-mm extension ring)

Instantaneous Field[b]:

1.3-mrad	2.5-mrad

Focusing: Motor-driven remote, and manual

Mount: Quick-release bayonet type

DETECTOR

Type: Indium antimonide (InSb) photovoltaic

Spectral Range: 2 to 5.6 μm

Coolant: Liquid nitrogen, stored in a 100-cm^3 Dewar flask, permitting more than 4 hours of operation between refillings.

Footnotes

[a]Measure from camera picture plane located at the dividing line between cover and camera body.

[b]Fifty percent contrast or better.

DISPLAY UNIT 102B

TYPE

All-electronic, with professional TV-monitor picture tube utilizing magnetic deflection and random-line interlacing, selectable picture size, dual-isotherm presentation and preset photographic recording mode.

DISPLAY

Picture Tube: High definition type (10 kV accelerating potential), medium persistence (P4) phosphor.

Picture Sizes: (a) 90x90-mm (3.5x3.5-in) for direct viewing, and
(b) 67x74-mm (2.5x2.9-in) for photographic recording.

Picture Field Frequency: 16 per second

Line Frequency: 1600 per second

Raster Lines per Frame: 210 (interlaced)

Resolving Power: 140 standard lines

Features: 500 kHz spot wobbling, random line interlacing, daylight viewing, plug-in control units

TEMPERATURE MEASUREMENT

Object Temperature Range: -30° to +850°C in sensitivity steps and 7 f/stops, i.e.,

f/1.8	-30° to +190°C
f/2.5	0° to +240°C
f/3.6	+50° to +300°C
f/5.1	+80° to +390°C
f/7.2	+100° to +500°C
f/10	+140° to +660°C
f/14	+200° to +850°C

Temperature range extended to +2000°C by inserting gray-filter in turret.

Minimum Detectable Temperature Difference: Less than 0.2°C at +30°C object temperature.

Isotherm Functions: Dual or single, variable 2 to 60 percent of selected temperature range; levels adjustable continuously and independently.

Filter Turret: Accepts up to 8 infrared gray and/or spectral filters.

PHOTOGRAPHIC RECORDING

Camera adapter fittings for Polaroid® Land Camera Back, standard 35-mm, 6x6-cm still cameras, and 16-mm cine camera.

SYSTEM

Operating Temperature Range: -15° to +55°C

Storage Temperature Range: -20° to +70°C

Power Requirements: 115 or 230 VAC ±10 percent, 200 VA single phase, 50 to 400 Hz

DIMENSIONS

Camera Unit: 200x240x500-mm (WxHxL) (7.9x9.5x19.7-in), 13.5-kg (30-lb)

Display Unit: 450x200x530-mm (17.7x7.9x20.8-in), 23.7-kg (52-lb)

Interconnection Cables: 6-m (20-ft) standard
15-m (50-ft) optional
30-m (100-ft) optional

TRANSPORT

The two units are packed individually in two separate transport cases, the contents of which are arranged as follows:

IR Camera Transport Case:

Camera Unit Model 680
IR-Lens 680S 134/1:1.8/10
Interconnection Cable (6 m)
Operating Manual
Spare Parts Kit

Display Transport Case:

Display Unit Model 102B
Power-Line Connection Cable
Technical Description Booklet
Mounting Bezel for photo-recording

INITIAL DISTRIBUTION

USAF/RDPA	1
USAF/RDQRM	1
USAF/XOOFA	1
AFSC/INA	1
AFSC/SDA	1
AFSC/DLCAW	1
AFSC/DPSL	1
AFSC/SDWM	1
TAC/DRA	2
TAC/XPSY	1
AFAL/AA	1
AFAL/TEM	1
AFAL/RWM	1
AFAL/RW	1
ASD/YHEV	1
ASD/XRE	2
SD/YFEI(Armament)	1
ASD/ENO	1
ASD/ENFEA	1
ASD/ENASA	1
ASD/YPEX	1
ASD/RWS	1
ASD/RWR	2
ASD/SD (Tech Dir)	1
ASD/SD7	2
ASD/SD5EI	1
ASD/SD4T	2
AFFDL/FE	1
AFFDL/FGL	1
AFFDL/FX	1
AFFDL/FY	1
AFML/MX	1
AFML/LL	1
AFML/MB	1
AFML/LP	1
AFLC/MMWM	1
Ogden ALC/MMNOP	2
AUL (AUL/LSE-70-239)	1
ATC/XPQ3	1
NASC AIR-5325	1
NASC AIR-5324	1
ODDR&E/TST&E	1
DARPA/TIO	1
NASY AIR360E	1
USAF/AFSC Liaison Office	6
CO, NWC/Code 456	2
CO, NWC/Code 533 (Tech Lib)	1
CO, NWC/Code 4063	1
CO, NWC/Code 40903	3
CO, NWC/Code 3301	1
CO, NWC/Code 335	1
Redstone Sci Info Cen/Ch Documents	2
CO, USN Wpns Lab/MAL	1
CG USAMICOM/AMCPM-CT-E	1
DDC	2
CINCPACAF/IGFW	1
ADTC/PP	1
ADTC/TE	1
SOF/DR	1
TAWC/DT	1
TAWC/FTS	1
ADTC/XR	2
TRADOC/ADTC/DO	1
AFATL/DLOSL	2
ADTC/SD	1
ADTC/SDM	1
ADTC/SDE	3
ASD/SDO	1
ASD/SDM	1
USAF Academy (Dean)	1
SAC/XPHN	2
SAC/DOXT	1
SAC/LGWC	1
AFAL/NVA-679A	2
ASD SD-65	1
TAWC/TEFA	1
Philco-Ford Aeronutronics Div	1
Rockwell International, Columbus	1
Hughes Aircraft Co.	1
Martin-Marietta	1
Rand Corporation	1
USAF (AF/SAMI)	1
TAWC/TRADOCLO	1
AFIS/INTA	1
AFATL/DL	1
AFATL/DLB	1
AFATL/DLMA	1
AFATL/DLM	1
AFATL/DLMI-3	4
AFATL/DLOU	1

(The reverse of this page is blank)